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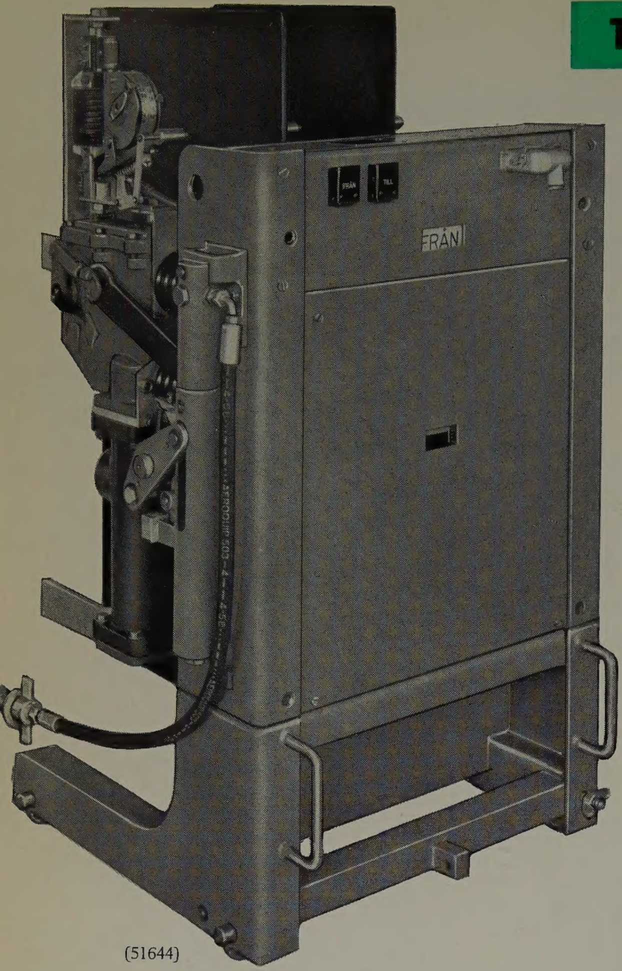
7-8

The new Asea induction motors under manufacture in the Örjan Factory of Västerås. (F 464)



(51644)

10/12 kV • 400 A • 150 MV

HKL

OIL-MINIMUM CIRCUIT-BREAK

— the small circuit-breaker with the large possibiliti

Built-in spring-closing gear, for use also with high-sp auto-reclosing

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Truck-type or fixed mounting

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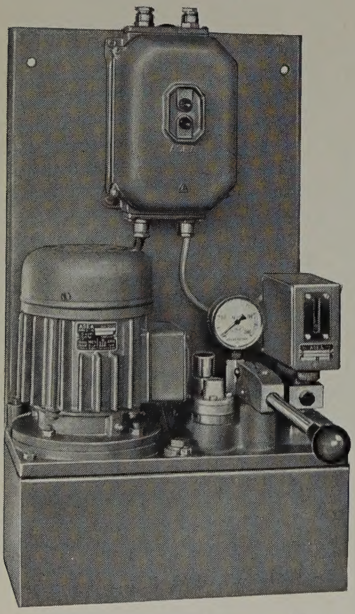


(51647

The spring-closing gear can be cocked manually, with a lever or by means of a built-on hydraulic mechanism. In the latter case the above pumping set is also required, which automatically cocks the closing spring. This pumping set can be utilised for several circuit-breakers.

ASEA

10/12 kV • 400 A • 150 MV

EW 150–1,500 H.P. INDUCTION MOTORS

ns Hedström and Elon Broström, Machine Design Department, Västerås

U.D.C. 621.313.333
Asea Reg. 443

*e Asea series of ventilated, enclosed induction motors
ratings of 150–1,500 h.p. has been redesigned, and,
conjunction with this, the external design of the mo-
s has been made more practical and more attractive.
e new design is described.*

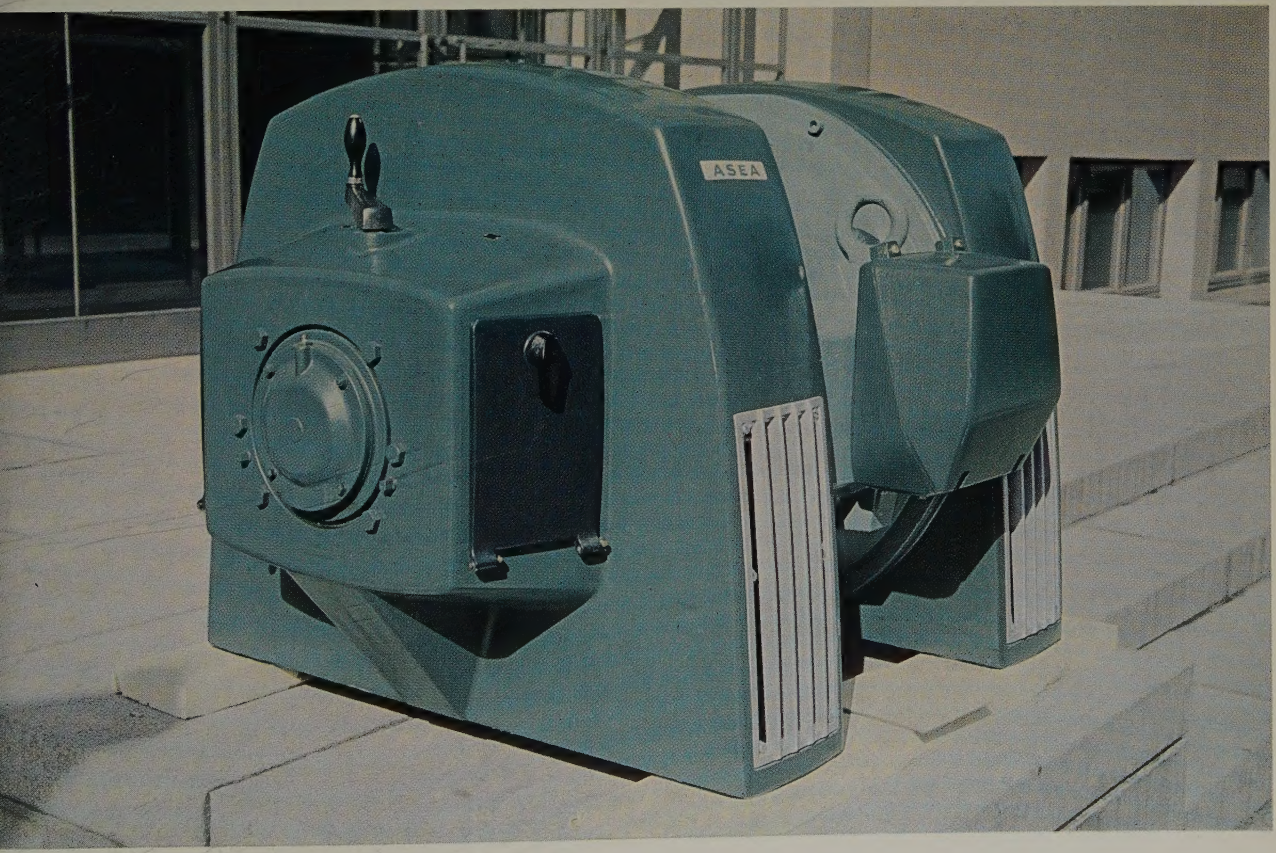
out 1910, Asea developed a new series of induction
tors which was given the type designation M. During
e later part of the 1920's, the motors in question
re redesigned as far as the vital parts were concerned,
e design then being adapted to the methods of pro-
ction and types of winding in use at that time.
ce then, the series, which was given the type de-
nation MA, has continued to be manufactured with
ry few alterations to the design. However, during
cent years, the availability of new materials and new
pes of winding justified the redesigning of the vital
rts. In conjunction with this, the other parts were
o redesigned, thus giving the motor a more practical and attractive appearance (Fig. 1). The new motors, which have been given the type designation MAD, are manufactured for the output range 150–1,500 h.p. and for voltages up to 6.6 kV.

WINDINGS AND INSULATION

The stator winding is usually designed as a double-diamond winding (Fig. 2), the coils being divided up laterally, with the consequent advantage that the slots do not need to be entirely open as is the case with ordinary diamond windings (Fig. 3). This reduces the no-load losses and the no-load current, resulting in a high degree of efficiency and a high power factor. This method of winding also has the advantage that it is easier to mechanise the various processes of manufacture. Thus, the coils are first wound into loops and then formed by a puller or spreader into the correct shape. For this purpose, specially manufactured machines are used.

The winding insulation is of class E [see Asea Journal 31 (1958):6, pp. 83–86]. The paper and cotton which were

*. 1. The external design of the new induction motor has
en made as practical and functional as possible with the
aring end-shields acting as feet. (F 507)*



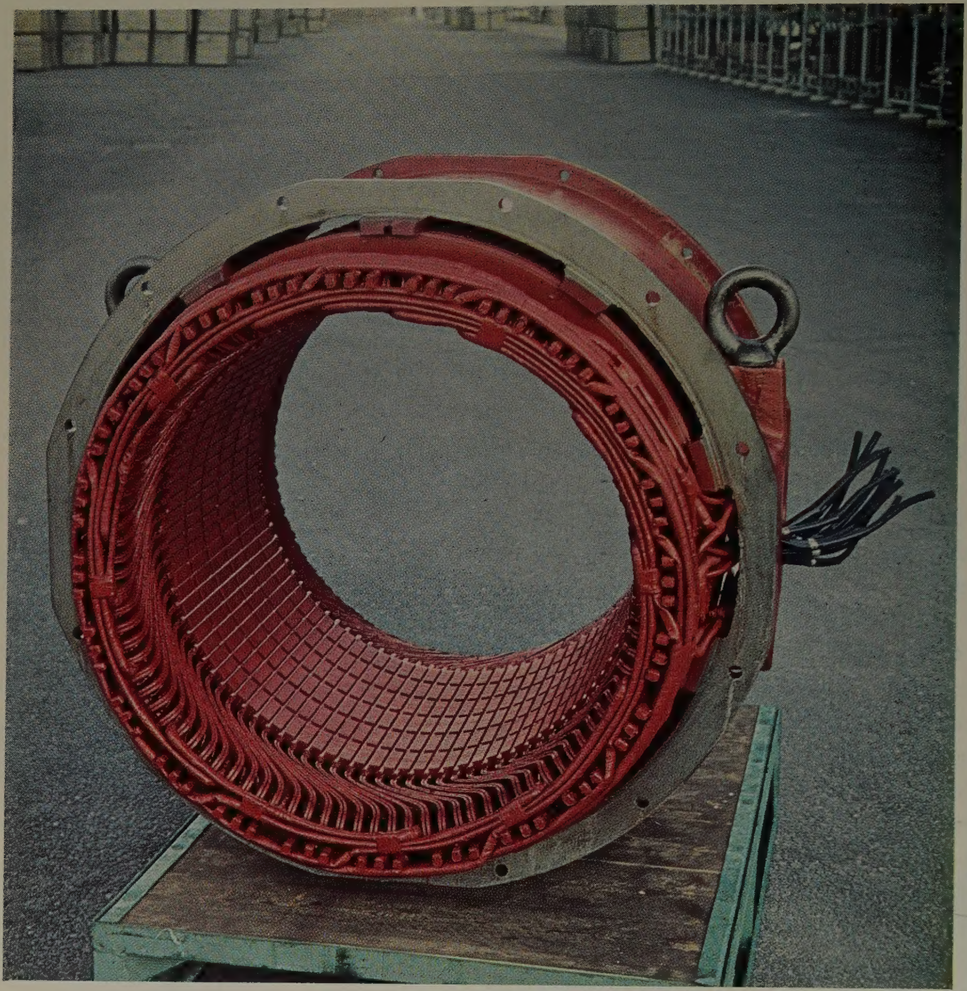


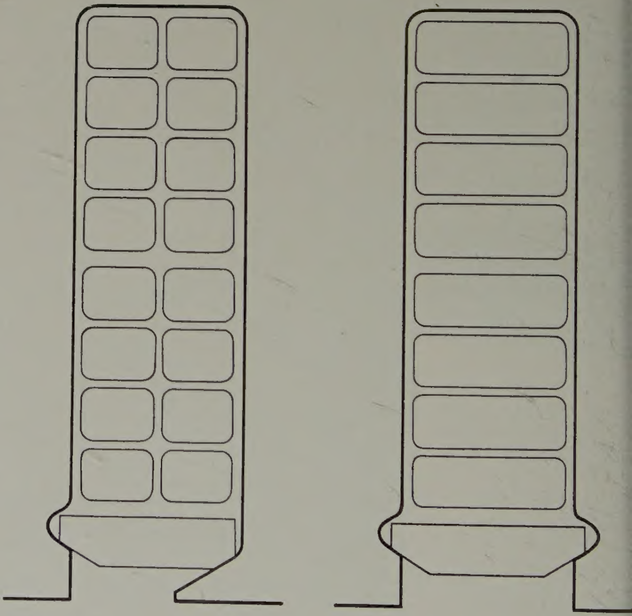
Fig. 2. Ready-wound a impregnated stator. T stator winding is general designed as a double-di mond winding with cla E insulation. (F 509)

previously used have now given way to new synthetic materials with high dielectric and mechanical strength. Thus, the main constituents of the conductor insulation are "Mylar", a polyester foil of American origin, in combination with the perhaps better known fibrous material, Terylene, which is also a polyester. The slot insulation also contains the above-mentioned plastic materials, but here, the paper material presspahn has been retained as a stiffener.

For the smallest types in the series mush winding with enamelled wire has been adopted. This type of winding is well known because of its use in the smaller standard series (MBRC etc.), but in this case it has been reinforced with plastic foil.

The rotor winding (Fig. 4) is a conventional barrel winding throughout, in which, however, the older type of insulation has been replaced by modern insulation of class E.

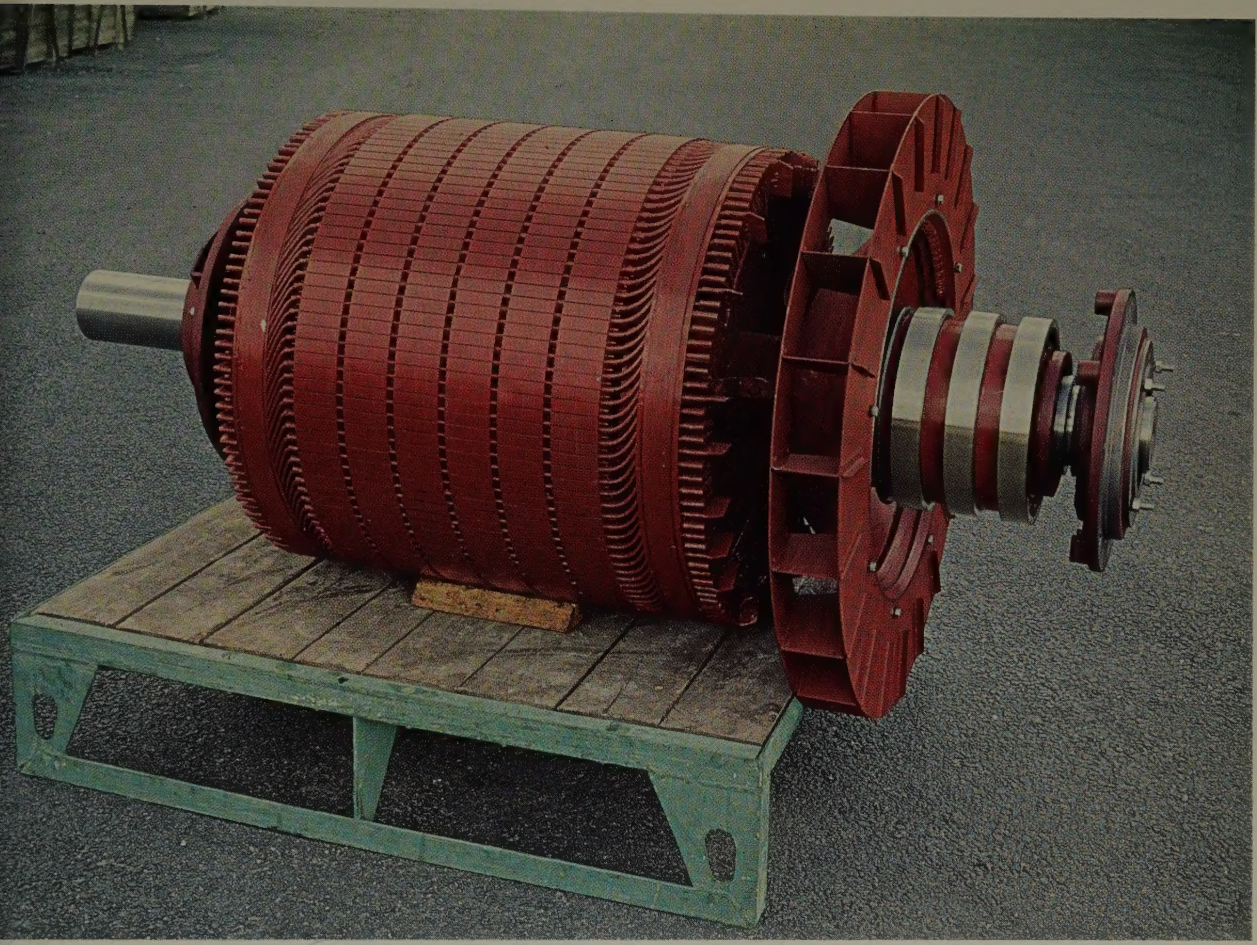
Great attention has been devoted to impregnation. This is carried out by means of a specially tested and carefully supervised dipping operation. By this means, the varnish thoroughly penetrates into the winding. On



Double-diamond winding

Diamond winding

Fig. 3. Half-open slot for a double-diamond winding and a open slot for a diamond winding. Compared with the othe the first-mentioned winding results in lower no-load losse and no-load current. (Fr 941)



4. Ready-wound and impregnated rotor. The rotor wind-
is a conventional barrel winding throughout with class E
lation. (F 508)

surface, a pigmented varnish is sprayed on, giving mooth and uniform surface providing protection nst oil, moisture, dust, etc.

. 2 and 4 show the wound and impregnated stator rotor, the latter complete with fan and bearing sing.

motors are manufactured and stocked to a certain nt for lower standard voltages, up to 550 V, making of the above-mentioned windings. For higher volt-, up to 6.6 kV, use is made of types of winding with lation of class A or class B, in both cases with slot lation of hot-pressed micanite.

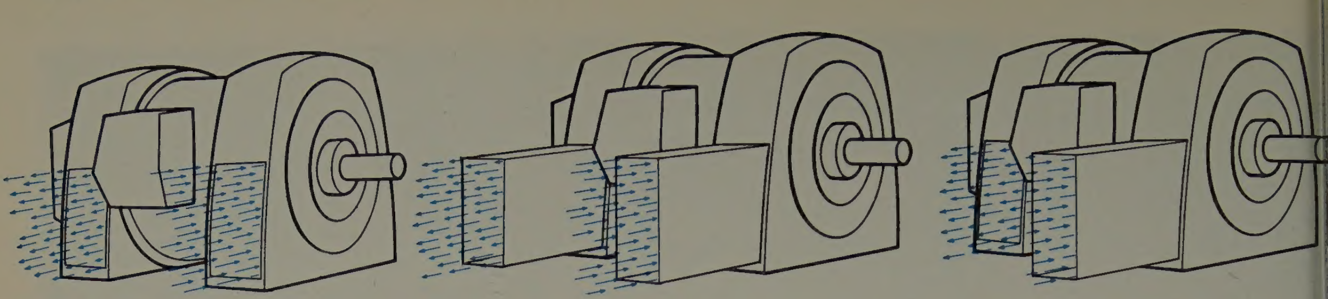
E DESIGN OF THE MOTOR

motor has been given a practical shape with the ing end-shields serving as feet, thus ensuring that motor is light, stable, and almost free from vibra-s. This design had previously been used by Asea two-pole and certain four-pole machines, and in e cases proved itself to be extremely advantageous. Therefore, when this new series was planned, this design was selected for the entire series.

Experience has shown that dust from the brushes in the slip-ring housing can damage the insulation, particularly that in the rotor winding. For this reason, the slip-ring housing in this new motor has been separated from the motor itself by means of the ventilation fans, and some of the ventilation air is led through the slip-ring housing, with the result that the dust from the brushes does not enter the machine and that long-life brushes can be used.

The motor is available either with brushes in continuous contact with the slip-rings or with short-circuiting, and brush-lifting, gear. It is also available in a squirrel-cage design (with the type designation MBD) with about 120 per cent starting torque and a starting current 5–6 times the normal current in the case of direct-on-line starting.

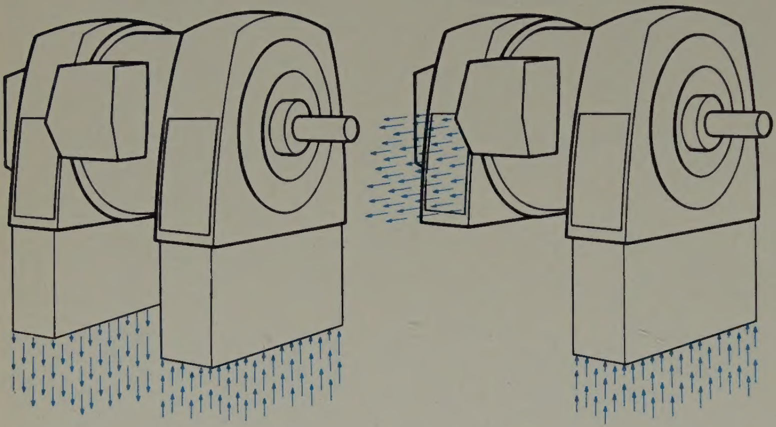
In its basic design, the machine is fitted with feet and one shaft-end (disp. 217), but other designs are also made. Thus, for example, it can be obtained as a flange motor (after changing the bearing end-shields), or with two shaft-ends.



a) Form E. The inlet and outlet for the air through grids in the bearing end-shields.

b) Form P. The inlet and outlet for the air through air ducts.

c) Form P+E. The inlet for the a through an air duct and the outl through the grid in the bearing enc shield.



d) Form O. The inlet and outlet for the air through channels in the foundation.

e) Form O+E. The inlet for the air through a channel in the foundation and the outlet through the grid in the bearing end-shield.

Fig. 5. Form E is the normal one, b other forms can readily be obtained wit the aid of covers and air ducts or a channels. (Fr 942)

It is normally of form E, that is to say, it is of drip-proof design (Fig. 5 a). However, other forms can readily be obtained with the aid of covers and air ducts or air channels. Fig. 5 b shows form P (the inlet and outlet through air ducts) and Fig. 5 c the variant P+E (inlet through an air duct and a free outlet); Fig. 5 d shows form O (the inlet and outlet through channels in the foundation and 5 e a variant O+E (the inlet through a channel and a free outlet). Forms P and O are particularly suitable in premises where the air contains a great deal of dust or corrosive matter; they also suppress the noise of the motor.

Normally, the motor is fitted with rolling bearings, but if desired, it can be supplied with sleeve bearings. The bearings are built into separate bearing housings which makes possible the accurate adjustment of the air-gap.

The rolling bearings are fitted with grease valves with lubricating nipples of Alemite type, which are now in general use throughout the entire world. The corresponding grease gun is known as Tecalemite. A low-pressure grease gun is the more suitable since it provides more grease per stroke (about 2 g as against 0.5 g fc the high-pressure grease gun). The nipples can easil be changed to those of SKF type (thread 1/8").

When the motor is assembled in the workshops, th stator and the bearing housings are adjusted in relatio to the bearing end-shields and fixed by means of dow pins. This ensures that all the parts remain in the sam position after dismantling, for example, if the slip-rin are to be changed.

The alignment of the motor with a driven machine carried out in the ordinary way with the aid of shin placed between the motor and the foundation. The fi ing bolts are readily accessible after the grids over th ventilation openings have been removed.

All the terminals have contact clamps, thus obviatir the need for soldering. The motor has one terminal bc for the stator terminals and one for the rotor terminal one on each side of the stator. The boxes have conne tion openings in accordance with Swedish Standard Fl 2 33 and 40 (Asea 12, 13 and 14).

HE FIRST MULTI-ROPE WINDER IN BELGIUM

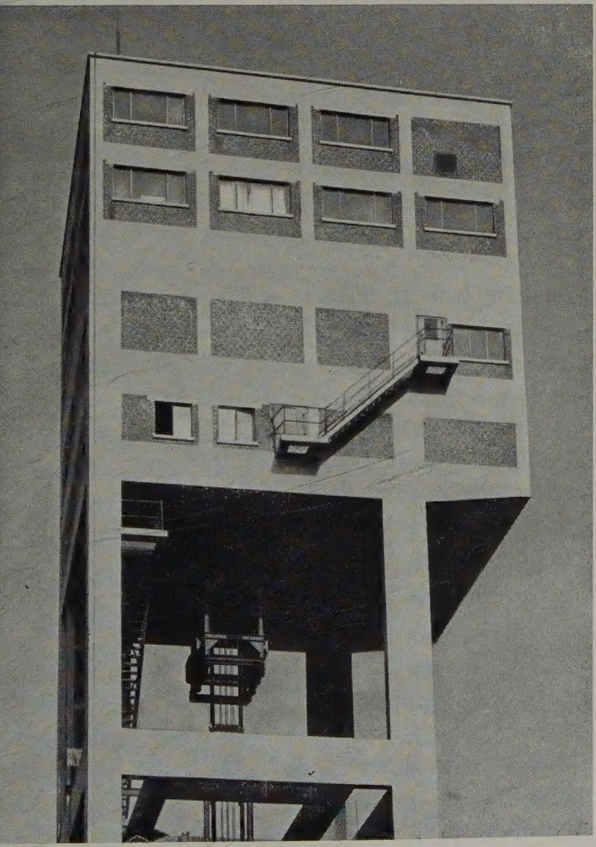
wier Francotte, Ingénieur en Chef, Charbonnages de l'Espérance et Bonne Fortune, Montegnée-lez-Liège,
lgium, and Franz Landau, Industrial Engineering Department, Mining and Transport Section, Asea,
isterås, Sweden

U.D.C. 622.67
Asea Reg. 632

e first friction-drive winder in Belgium with four pes is operated by a winding engineman, but works ni-automatically. It is ultimately intended to be oper-ed from the shaft by means of pushbuttons. The useful d 3.6 – 4.4 tons represents the contents of four coal rs which are carried in multi-deck cages designed for uble hoisting. The hoisting speed is 12 m/s (39 ft/s), e 900 h.p. hoist motor is Leonard-driven and the dia-eter of the pulley is 1.8 m (6 ft). The winder is also ed to carry men and equipment.

e first multi-rope winder in Belgium has been working the Espérance et Bonne Fortune coal mine at Mon-gnée near Liège since August 1957. The winder, which as supplied by Asea, was intended to increase produc-on in an existing shaft which was previously served an older type of winder placed at ground level.

. 1. The new concrete headframe at the Espérance et nne Fortune coal mine at Montegnée near Liège in Belgium. 2726)



The new concrete headframe, as shown in Figs. 1 and 2, which was built around the existing concrete headframe carrying the head sheaves, was planned in such a way that the new winder could be entirely installed without interrupting hoisting in the shaft. The demolition of the old headframe and the running-in of the new winder took place during the normal holiday period so that it was possible to take the installation into use as soon as work was resumed.

The winder is intended for the double hoisting of coal cars in four-deck cages and for the transport of men and equipment. The installation was planned in close collaboration with the engineers of the mine who, because of their experience of this type of service, had special requirements concerning the operation of the winder.

The height of the headframe is 42 m (138 ft); its lower part is completely open since it is placed over a shaft for the return air. The entire headframe weighs about 1,800 tons. It has been designed to withstand the forces which might arise in the case of a rope rupture.

The winder is situated at a level of 35 m (115 ft). The Leonard converter, the brake equipment and the distribution systems for high, and low, voltage are at a level of 31 m (102 ft). The cables for the high voltage and for signalling, the air-conditioning fan, and deflection sheaves, are at the 28 m (92 ft) level.

At the 18 m (59 ft) level there are bumper beams of a new type mounted on rubber dampers; above these are safety wedges designed in accordance with Belgian safety regulations. The shaft limit-switches and synchronising contacts are located at the 12 m (39 ft) level. At the 5 m (16 ft) level there is a bank for the cars. At ground level there is an auxiliary bank for the transport of equipment.

Under each of the four concrete pillars of the headframe there is a room with jacks which are intended to correct any settlement of the headframe, which is built on relatively weak ground. The headframe is carried by, in all, 54 piles.

All the building work was planned and carried out by Société des Pieux Franki in accordance with instructions from the mining company.

Fig. 3 shows the winder which is mounted in the upper storey of the headframe. The machinery for a passenger lift in the headframe, which was also supplied by Asea, can be seen in the illustration.

DATA

The mine winder is designed with the following data:

Double hoisting with two cages

Number of decks per cage	4
Number of cars per deck	1
Useful load per car	900 – 1,100 kg
Total useful load	3,600 – 4,400 kg
Weight of four cars	1,400 kg
Weight of cage	3,500 kg
Hoisting distance	max. 850 m (2,800 ft)
Hoisting speed	max. 12 m/s (39 ft/s)
Number of ropes	4
Rope diameter	22 mm (0.9 in.)
Diameter of pulley	1.8 m (6 ft)
Rating of winder motor	900 h.p., 750 r/m, 600 V

The winder motor is driven by a Leonard converter with a 6 kV synchronous motor.

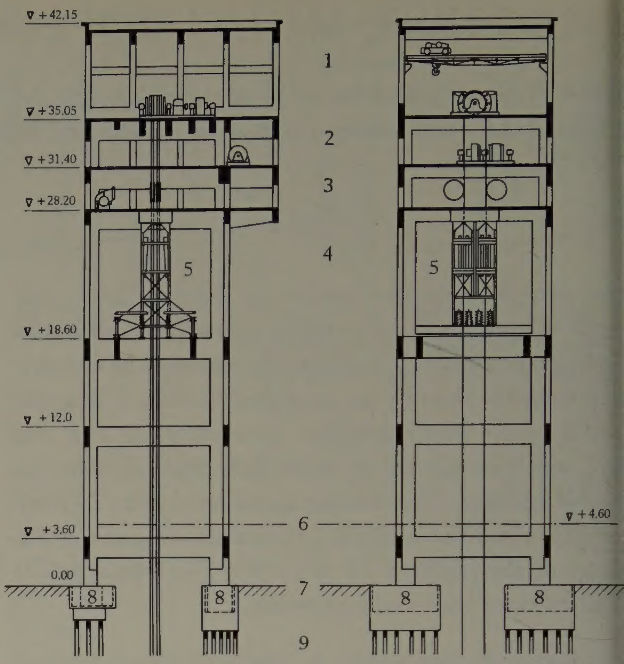
MECHANICAL EQUIPMENT

The pulley has two separate, combined service and emergency brakes which are completely independent of each other, each of which works on its own brake drum. The emergency brake is applied with a force which varies depending upon whether the cage is in the middle of the shaft or near the top. The pulley has four rope treads made of a plastic material fastened by means of wedged wooden blocks.

The precision gearing is a completely enclosed unit which "floats" on springs and is connected to the pulley by means of a flange coupling. All the bearings in the pulley and gear are SKF roller bearings. The winder motor is connected to the gear by means of an elastic coupling and has a built-on tachometer generator for speed regulation.

Fig. 4 shows the compressed-air equipment for the brakes, which is located in the storey beneath the winder. Next to the cabinet containing the compressed-air valves and so on there is a pressure tank which is linked with the compressed-air network of the mine and with the automatically operated standby compressor in the foreground.

The upper ropes are Lang's lay ropes, two with right-hand lay and two with left-hand lay, and have a diameter of 22 mm (0.9 in.). The weight of each rope per metre is 1.9 kg and the total breaking load for all the four ropes together is 130 tons. The balance rope is a normal flat rope having a weight of 7.6 kg per metre.



1. Winding floor
2. Floor for the Leonard converter and electrical equipment
3. Floor for cables, fans and pulleys
4. Safety wedges
5. Bumper beams
6. Bank
7. Ground level
8. Room containing jacks
9. Piles (54)

Fig. 2. A section of the headframe. Level in metres. (Fr 926)

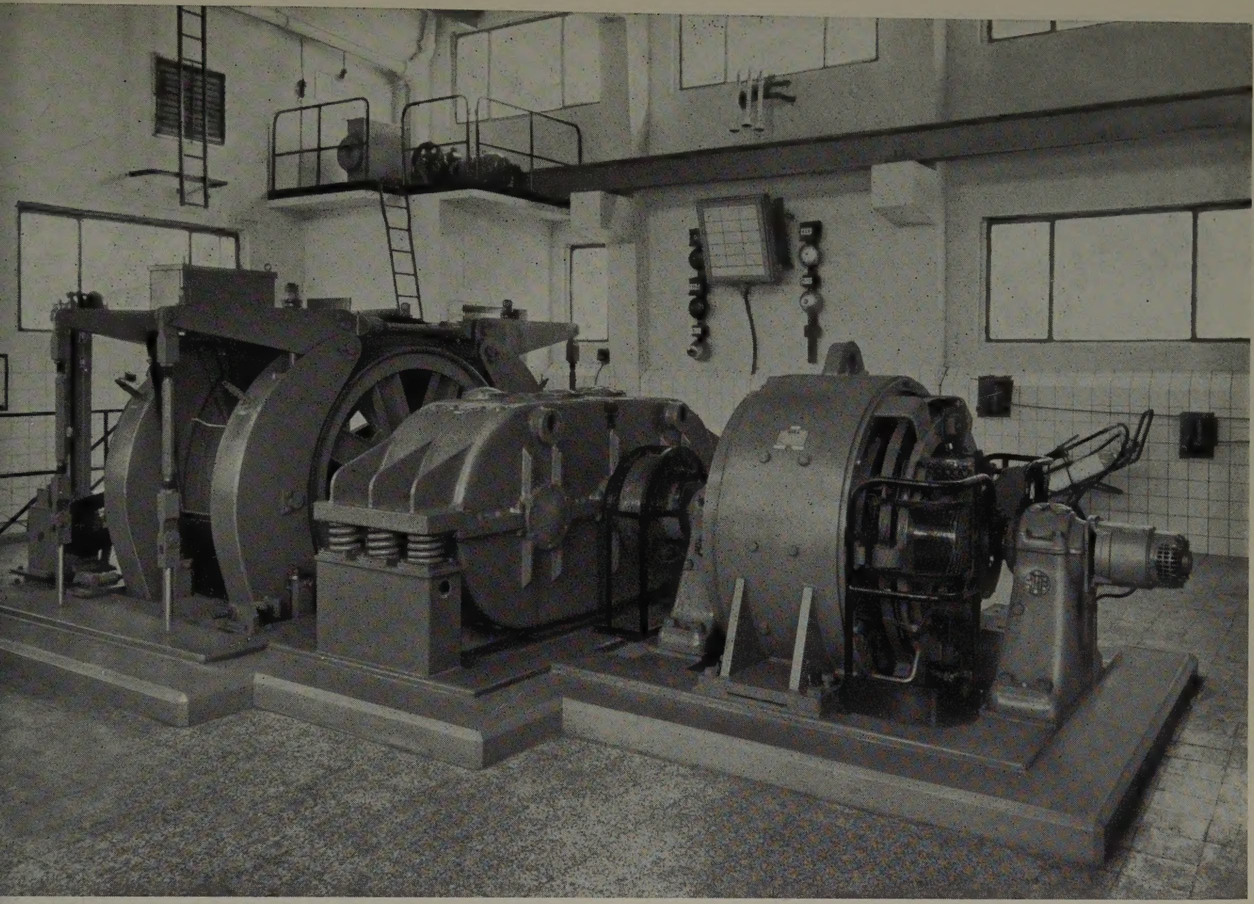
The upper ropes are fixed to the one cage direct and to the other by means of compensating gear. The rope connections are such that individual adjustment of the rope length is possible on the one side.

The rope attachments were supplied by the German firm Heur-Hammer in accordance with the drawings of the mining company.

ELECTRICAL EQUIPMENT

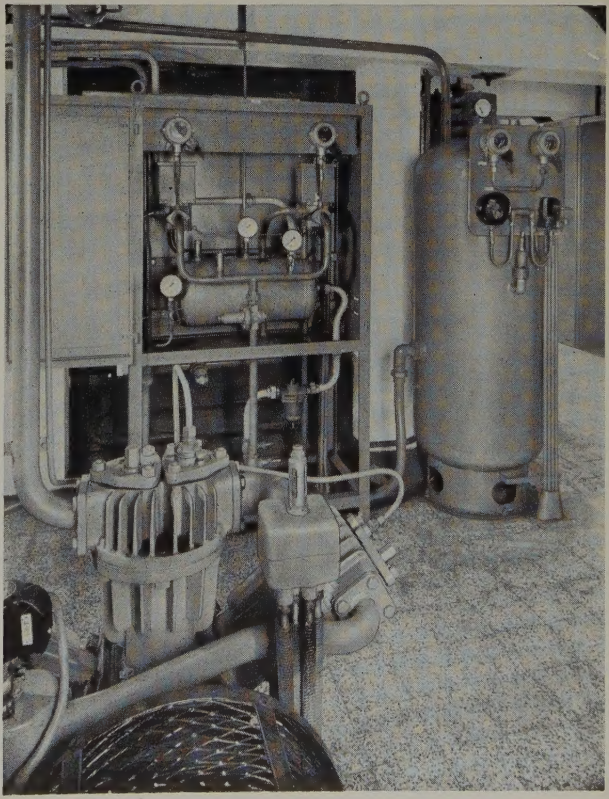
The storey beneath the winder also contains the Leonard converter as shown in Fig. 5, the metadyne amplifier for speed regulation and a standby metadyne as shown in Fig. 6, the 6 kV high-voltage switchgear as shown in Fig. 7 and a metal-clad distribution board for the 380 V low-voltage distribution system in accordance with Fig. 8. This board is fed from an auxiliary transformer, rated at 30 kVA, 6,000/380 V, 50 c/s, in the 6 kV switchgear and provides current for the auxiliary equipment of the winder. The synchronous motor of the Leonard converter is pushbutton-operated and is started by means of a reactor which, along with its circuit-breaker, is placed in the 6 kV switchgear.

Fig. 9 shows the control desk which stands in front of the winder. To the left of the desk and at right angles to it there is the control panel as shown in Fig. 10, the



3. *The winding room in the uppermost storey of the dframe. In the background, to the left, the machinery the Asea passenger lift in the headframe. (52715)*

Fig. 4. Compressed-air equipment for the brakes of the mine winder. In the foreground, the standby compressor. (52717)



cubicle of which, D, contains the necessary equipnt for the pushbutton starting of the Leonard coner, while the other cubicle, E, houses the operating protective relays for the winder. At the front of the el the fault-indication board which gives the reasons any possible emergency stopping of the winder can seen, as well as the voltmeter for the d.c. exciter en from the Leonard converter, voltmeters and amers for the 6 kV system, the power-factor meter for synchronous motor and ammeters and regulating stors for its excitation current.

lly, Fig. 11 shows the winder regulator which is en off the winder shaft. This contains the selsyn smitter for the electrically driven depth indicators ch are placed on the control desk and magnet cons which give automatic retardation impulses for slowdown at the various levels. Further, there is a camrated potentiometer rheostat for the electrical overd protection which shadows the speed during the re winding process and brings about emergency stop if the speed at any point in the shaft exceeds the nitted value. A synchronising device automatically s the entire apparatus into the correct position if its

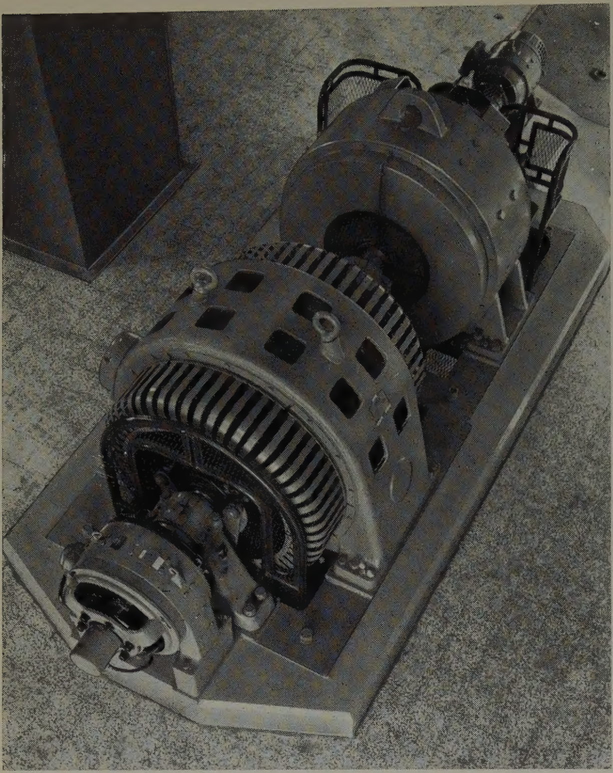


Fig. 5. The Leonard converter with d.c. generator rated at 650 kW, 630 V, and a synchronous motor rated at 800 h.p., 6 kV, 1,000 r/m with exciter and constant-voltage exciter for the excitation and operating current. (52719)

rotational angle no longer corresponds with the position of the cages in the shaft because of the creepage of the rope over the pulley.

To the left of the large winder regulator there is a regulator for deck-changing which is driven from the winder by means of a chain and which is only in circuit during deck-changing. It then regulates automatically the desired acceleration and retardation so that the entire operation of deck-changing is carried out with great precision merely by means of an impulse from the winding engineman.

REGULATION AND OPERATION

The speed of the winder is regulated by means of a metadyne amplifier in accordance with a closed-loop system. The actual speed is represented by the voltage of the tachometer generator which is driven from the winder motor, while the set speed is obtained as a reference voltage on a potentiometer in the control desk. The potentiometer is regulated by means of the lever to the right in Fig. 9.

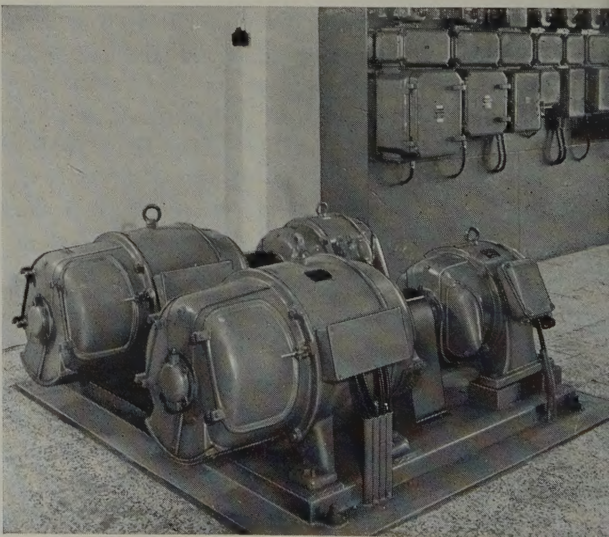
The difference between the voltage of the regulating potentiometer and that of the tachometer generator represents the speed error signal. This is fed into the main field winding of the metadyne amplifier whic feeds the excitation winding of the Leonard generato The voltage of the latter, and with it the speed of th winding motor, is consequently regulated in such a wa that the speed error is reduced to a minimum. Thus, certain position of the control lever corresponds to certain winding speed, virtually independent of the siz of the load and its direction of travel. The speed can b regulated accurately and continuously from 12 m (39 ft down to 0.1 m (4 in.) per second or even less.

The equipment is so designed that, in the future, th winder can be operated by means of pushbuttons fror the various levels, if the necessary apparatus is installe in the shaft.

At present, the winder operates semi-automatically i such a way that the levels to which the cages are to b sent are selected in advance by means of a change-ove switch on the control desk. The winding enginema starts the winder by means of the control lever, where upon the speed is either increased or reduced at a con stant rate, even though the lever is moved very quickl from one position to another. When the cage approache the level selected, the winder is automatically retarde to creeping speed even though the control lever has no been moved into the corresponding position. The cag is stopped at the level in question by moving the contr lever into the neutral position.

Thus, the winding engineman can always intervene an regulate the speed, and retard or stop the winder, bu if he neglects to do this in the vicinity of the destinatio level, slowing up takes place automatically. The followin types of running can be selected by means of a servic selection switch placed between the depth indicators o the upper part of the control desk.

Fig. 6. The metadyne converters, of which one is a standb (52720)



oisting

is position on the service selection switch corresponds the normal double hoisting of coal or rock in cars. oisting is between the end levels, and the two cages e loaded simultaneously with the aid of automatic ading devices. The hoisting speed is 12 m (39 ft) per cond and acceleration and retardation 0.75 m/s^2 (2 ft in./s^2). Hoisting to the intermediate levels is also pos- ble and these are then selected in the same way as is scribed below for men hoisting.

en hoisting

ven when the controller is set at full speed, the latter limited in this case automatically to 7.5 m/s (25 ft/s) d the acceleration and retardation to 0.5 m/s^2 (1 ft in./s^2).

en can either be carried in the two cages between the d levels or in either one or the other cage between o optional levels in the shaft. A cage selection switch uated immediately below the service selection switch akes it possible to select winding with:

Cages A+B
Cage A
Cage B

n the table part of the control desk between the two erating levers there are two operating switches for ch cage by means of which it is possible to select the per and the lower levels between which the respective ges are to be wound. These levels are shown simul- neously on the indicating-lamps alongside the depth dicators. In all, there are six levels in the shaft be- een which the winding of men and material can take ace.

spection of the shaft

e winding speed is limited automatically to 1 m/s ft/s) even though the controller is set at full speed.

ork on the shaft

this position of the service selection switch, the speed n be regulated to extremely low values (a few centi- etres per second), which is essential for the carrying t of special work in the shaft. In cases such as this, ry small movements of the cage may be necessary.

ECK-CHANGING

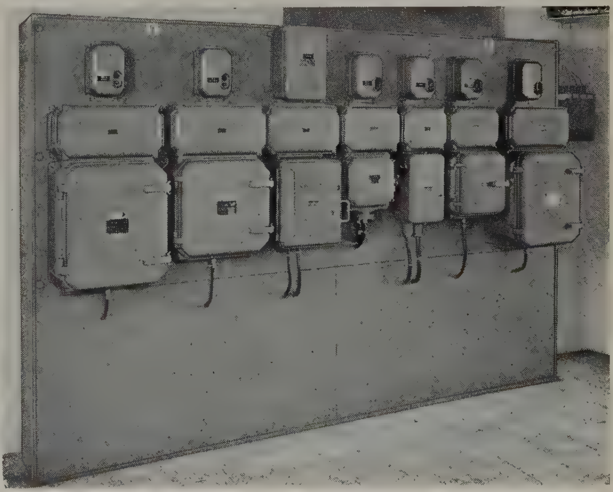
uring normal coal-hoisting, there are three deck changes ter each winding operation, the loaded cars in the two ges being run out and empty ones run in, or vice versa. oving platforms which are let down at the various vels on to the floor of the cages compensate for the vertical movement of the cages as a result of variations in the stretch of the rope during the loading and unloading operations.

Fig. 7. The 6 kV switchgear. (52721)

At the bank at the surface, the loaded car on the bottom deck of the cage is first taken out and replaced by an empty car, at the same time as, at the charging station at the bottom of the shaft, the empty car on the top deck of the cage is replaced by a loaded one. The platforms are then pulled in and the cages are rapidly moved one deck, whereupon the upper cage with one empty and three loaded cars is moved downwards. During this operation a regenerating torque corresponding to half that of the full load is obtained.

During the next deck-changing operation, the cages are in balance and the load torque is zero. After the third deck-changing operation, the upper cage has only one loaded and three empty cars at the same time as the lower cage has one empty and three loaded cars. This

Fig. 8. The 380 V metal-clad distribution board. (52725)



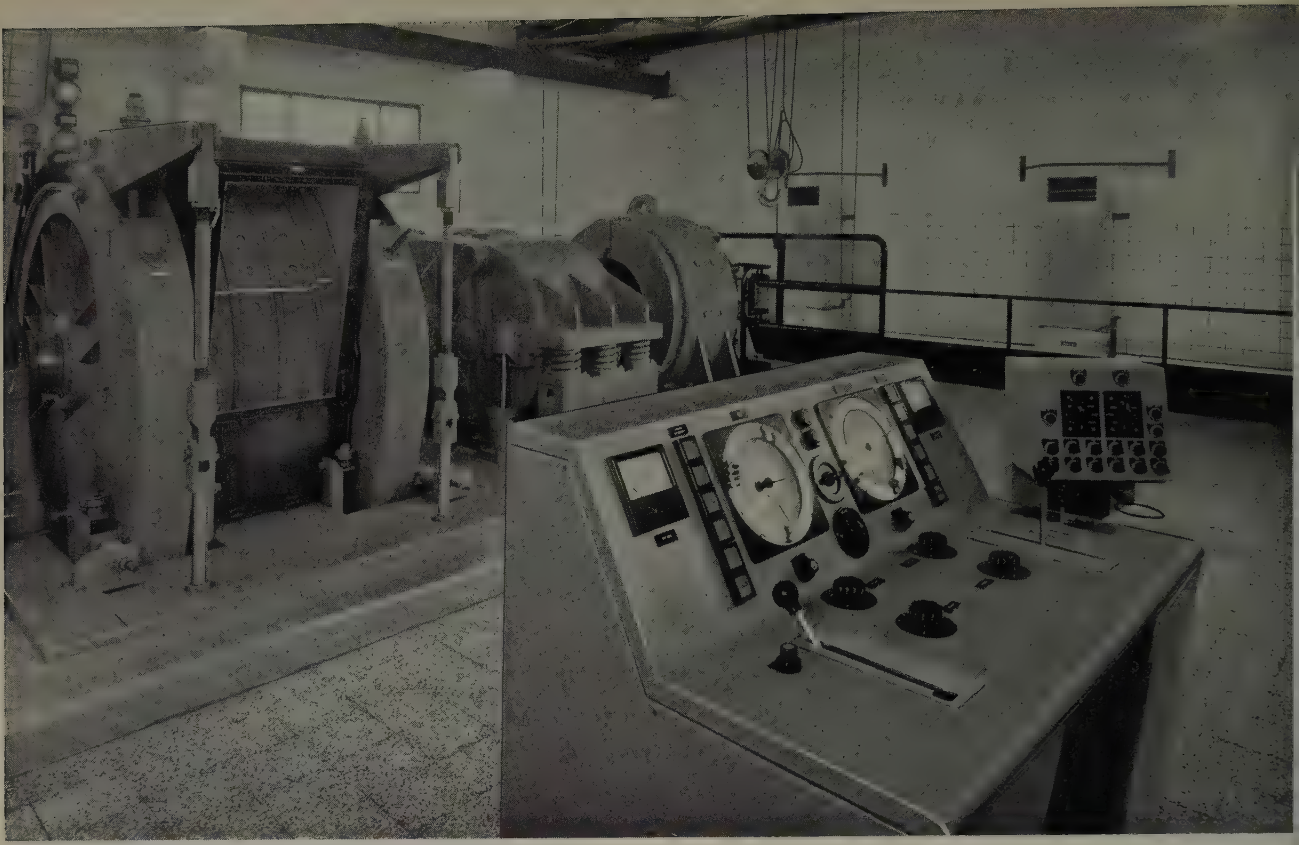


Fig. 9. *The control desk for the mine winder. (52714)*

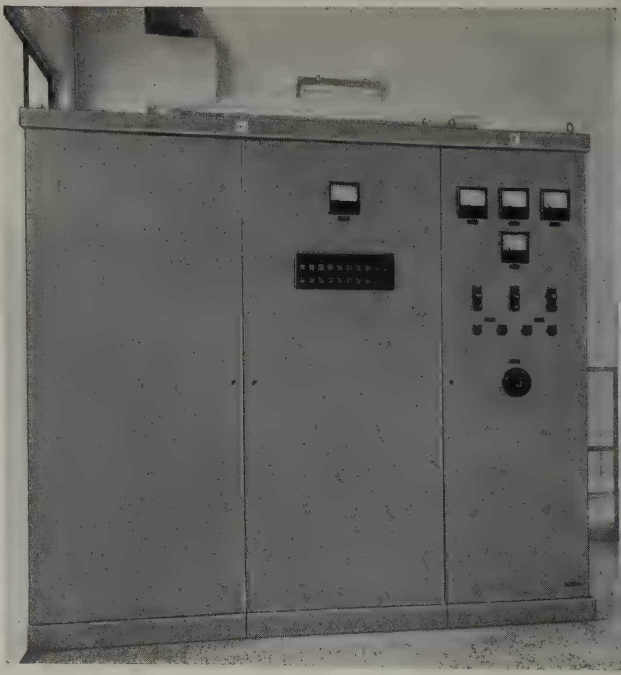
means that the motor has to overcome a torque equal to half that of the full load.

In the case of multi-deck cages, the time required for changing the cars usually has a considerable influence on the hoisting capacity of the winder. In the equipment supplied, the time required for changing from one deck to the next has been reduced to about 2 seconds, and by arranging automatic loading devices, it has been possible to reduce the time required for changing 8 cars on 4 decks to only 23 seconds.

Since the distance between two decks is 1.45 m (4 ft 9 in.), the speed when changing decks has been limited to about 1.5 m/s (5 ft/s) at the same time as the acceleration has been increased to 1.5 m/s^2 (5 ft/s^2) and the operation of deck-changing has been made automatic. For deck-changing, use is made of a small operating switch placed to the right of the control lever, which, in combination with the deck-changing regulator shown in Fig. 11, ensures that the winder automatically runs up to a speed of 1.5 m/s (5 ft/s) with an acceleration of 1.5 m/s^2 (5 ft/s^2) and then, with the same rate of retardation automatically returns to creeping speed. When the cage has moved one deck, which can be seen from marks on the rope, the winder is stopped by the winding engineman by putting the operating switch into the neutral position.

The service brake can also be regulated, when the speed has dropped to 1 m (3 ft) per second or less, by means of the brake lever to the left of the control desk which actuates a regulating resistor for an electromagnetic com-

Fig. 10. *Control panel with equipment for the pushbutton starting of the Leonard converter (cubicle D) and operating and protective relays for the winder (cubicle E). (52722)*



pressed-air regulator. This brake lever is really unnecessary, but it was put in at the special request of the customer in order to be able to influence the speed when changing decks if this should be necessary. It has, however, proved that the electric regulation alone gives the desired degree of accuracy for which reason the brake lever does not have to be used during winding. Naturally, by returning the operating switch for the deck-changing to its original position, the winder can be retarded or stopped before the cage has travelled the whole distance between the decks. Since the deck-changing regulator also contains a stop contact which can automatically stop the winder when the cages have moved one deck, this operation, too, can be carried out by means of a pushbutton when pushbutton operation from the shaft is installed in the future.

PULLEY AND ROPES

Since the diameter of the friction-drive pulley is equal to the distance between the centres of the cages, it has been possible to place the winder directly over the shaft without having to use any deflection sheaves.

Since the shaft is not entirely vertical, during winding the ropes are sometimes made to swing a great deal which means that they occasionally strike each other. In order to prevent these vibrations from being felt at the winder, at level 28 m (92 ft) two sets of guide sheaves have been installed, each set consisting of four sheaves which have the object of damping the vibrations and ensuring that the ropes go smoothly into the grooves of the friction-drive pulley.

Hitherto, however, the ropes have not suffered any damage and they will probably last longer than those on the single-rope Koepe winders in the other shafts.

AIR CONDITIONING

The three floors at the 35, 31 and 28 m (115, 102 and 92 ft) levels are completely enclosed and the air in them is kept above atmospheric pressure by means of ventilation equipment supplied by Svenska Fläktfabriken, an associated member of the Asea Group. Air is taken from outside and cleaned in automatic filters, whereupon it is forced from level 28 m (92 ft) up to the converter, and winding, rooms. At normal ambient temperature, the heat losses of the machines are sufficient to heat the upper machine rooms.

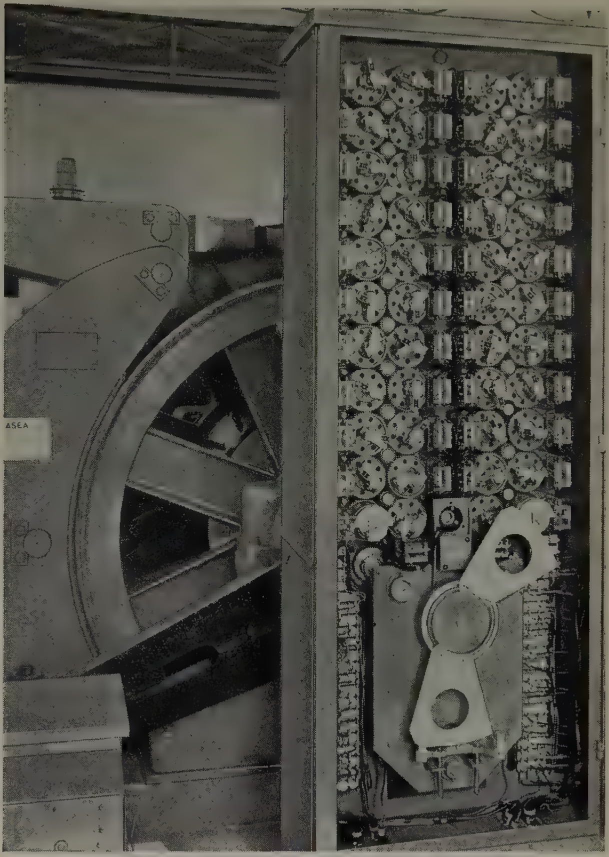


Fig. 11. Winding regulator with magnet contacts for the initiation of automatic slowing down at the stopping levels, overspeed protection, selsyn transmitter for the depth indicator and automatic synchronising gear. To the left, the deck-changing regulator. (52716)

INSTALLATION

The Asea equipment weighs as little as about 25 tons for the mechanical and the electrical parts together. The heaviest single part weighs only 4.5 tons, which greatly facilitated the work on the erection of the equipment. The lifting into place of the rotating machines was carried out in only 16 hours. After the old winding installation had been dismantled, the old headframe was demolished, cages and ropes put in, and the new winder was installed and commissioned over a period of only 10 effective working days.

FUSION REACTIONS RESULTING FROM DISCHARGES IN DEUTERIUM

Hans Witt, High-voltage Laboratory, Ludvika

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Asea Reg. 0666, 3877

After a short summary of the nature of the fusion process, an account is given of the part played by Asea in the experiments which have been, and are being, carried out at the Institute of Physics at Uppsala University. Among the subjects considered are experiments with straight discharge tubes, and the new experimental reactor with tubes of toroidal design. Finally, some possible solutions of the problem of the long-term confinement of plasma are suggested.

The production of energy by exploiting fusion reactions has in recent years been the subject of intensive research in many parts of the world. Asea have also felt it expedient to follow developments in this field closely; for example, by co-operating with various academic institutions. Asea have thus contributed to research, partly by providing financial support, partly by solving certain technical problems and producing certain items of experimental equipment.

There has been much speculation in recent years on the future of fusion-produced energy. Some physicists are now of the opinion that the difficulties to be overcome before the concept of economic power production from reactors is finally realised, are so great that there is probably little chance of success in this century, if ever. Others consider the present experimental models merely as prototypes of future power-producing reactors and expect development to be swift.

The champions of both sides can present sound arguments for their points of view. However, perhaps the most realistic outlook is to consider developments in the field of nuclear fusion as fundamental research carried out on a long-term basis. Nevertheless, should research lead to results of immediate practical value earlier than expected, Asea wish to be equipped and ready, through keeping a careful eye on developments, to make the new source of energy available to their customers with the utmost speed.

This article deals briefly with the part played by Asea in the experiments which have been, and are being, carried out at the Institute of Physics at Uppsala University. Some of the lines which future approaches to the problem may follow are then suggested, together with some of the difficulties which seem likely to arise. Emphasis has been laid on the many interesting and unconventional technical problems whose solution constitutes a condition for the success of further research on the same lines. The physics of the implied processes is only touched upon in so far as it seems to contribute to the proper understanding of the article, and then only very briefly.

THE NATURE OF THE FUSION PROCESS

The fundamental fusion reactions are quite well known, partly as a result of experience gained in the course of work with particle accelerators, and they have been thoroughly described previously [1].

The combination (or fusion) of light nuclei to form heavier nuclei results in the release of nuclear energy. A number of different fusion reactions are possible. Reactions (1) and (2) are perhaps the most interesting of them:

$$D + D \longrightarrow + He^3 + n + 3.25 \text{ MeV} \qquad (1)$$

$$D + D \longrightarrow + T + p + 4.0 \text{ MeV} \qquad (2)$$

When two deuterium nuclei (deuterons, designated by the symbol D) fuse, either helium (He^3) or the heavy hydrogen isotope tritium (T) is formed, with approximately equal probability. Simultaneously, a neutron (n) or a proton (p) is released, together with energy of the order of approx. 3.6 MeV or 5.8×10^{-13} Ws for each pair of deuterons. The total mass of the reaction products (on the right-hand side of the arrows) is somewhat less than that of the interacting deuterons, and this difference in mass is the cause of the release of energy.

In order that the reaction may take place, the deuterons must be supplied with a certain energy, viz. about one two-hundredth of the energy released when the reaction occurs. In other words, there is a possibility that the whole process may result in energy gain. The energy that can be gained as a result of fusion of all the deuterium nuclei in a litre of water corresponds to the energy released upon combustion of approx. 340 litres of petrol. Deuterium is present in immense quantities in the oceans. The extraction of this deuterium presents no difficulties and, if the process were to be carried out on a large scale, the cost would be approx. 10 Sw. öre (2 d.) per litre of sea water treated.

f the fusion process could be exploited as a means of nergy production, fuel costs would be at a minimum nd the world's reserves of fuel practically inexhaustible, vhile there would probably not be the same problem f disposing of radioactive products as there would be sing the fission process in uranium reactors. The energy eleased per deuteron would be considerably greater han stated in (1) and (2) on account of secondary usion reactions, for example (3), in which the tritium ucleus produced in (2) undergoes fusion with a deuerium nucleus.

$$) + \mathrm{T} \longrightarrow \mathrm{He}^4 + \mathrm{n} + 17.6\,\mathrm{MeV} \qquad (3)$$

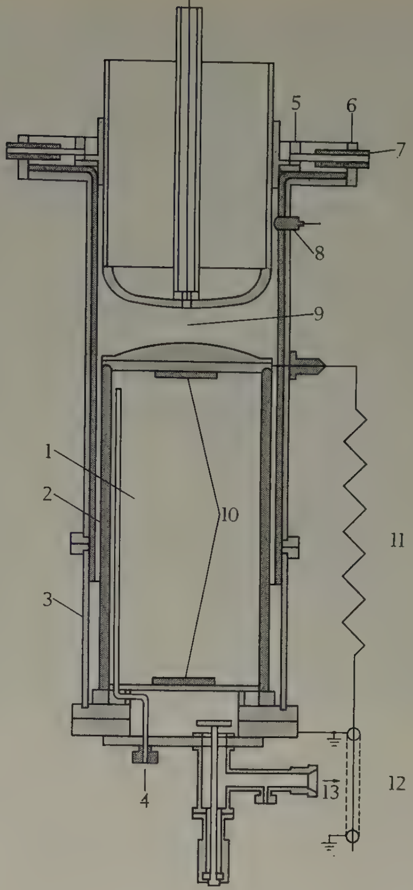
he potentialities of the fusion reactions are thus coniderable, but, unfortunately, so are the difficulties inolved in exploiting them in practice.

he energy necessary for the fusion reactions to take lace can be imparted to the deuterons in accelerators, nd these deuterons can then be fired at a stationary arget containing similar deuterons. It can, however, e shown that this energising process is wasteful and ot very effective, and that energy losses are too great or the operation to be economic. Fusion reactions can lso be started in hydrogen bombs using a fission bomb s a primer, but such reactions cannot be controlled.

t should, however, be theoretically possible to start and ontrol fusion reactions between the particles in deuerium gas if the particles are supplied with enough inetic energy; i.e., if the gas is heated sufficiently. At he temperature of several hundred million degrees ecessary for reaction to take place nearly all deuterium toms break up into ions and electrons. Matter in this articular state is called plasma, after the original defiition by Langmuir, to indicate that it is no ordinary as. A plasma has at least two characteristic properties: is a good electric conductor, and its internal losses ue to friction are small. The first property means that plasma can be confined by a magnetic field; the second at it is difficult to keep the confined plasma stable.

he properties of plasma had been studied by astrohysicists for some time before it occurred to anyone apply them to the problem of producing nuclear ergy. Many of the relevant fundamental physical laws ave been formulated by H. Alfvén [2].

ne of the main tasks of fusion research is to widen ur knowledge of plasma physics by means of laboratory xperiments with plasma, and to study its suitability for sion purposes. To this end, it is necessary to produce plasma; i.e., to supply the particles with great kinetic ergy and confine the plasma effectively within the nited space offered by what is often called a "magnetic ttle".



1. Discharge chamber
2. Porcelain tube
3. Coaxial aluminium tube
4. Deuterium gas inlet
5. High-voltage pole of the capacitor bank
6. Earth for the capacitor bank
7. Coaxial cable
8. Coil for measurement of the current derivative
9. Spark gap
10. Porcelain slabs
11. Voltage divider
12. Measuring cable
13. Pump connection

Fig. 1. The straight discharge tube with coaxial return and spark gap. Insulating material is indicated by dark shading and metal by light shading. (Fr 677)

EXPERIMENTS WITH STRAIGHT TUBES

A magnetic bottle in its simplest form can be created by introducing two electrodes into a gas-filled discharge tube and inducing a high current in the gas by discharging a capacitor bank. At the beginning of the process the current is spread over a wide cross-section. Electromagnetic forces between parallel lines of current, however, quickly compress the discharge to a slender column, termed a "pinch". In the course of this process, the gas is heated by a combination of adiabatic compression and resistive heating.

An experimental model based on this pinch effect was set up early in 1957 [3] and is still being used at the Institute of Physics at Uppsala. Deuterium gas is introduced into a straight porcelain tube (Fig. 1) with electrodes at both ends. The discharge tube is connected to

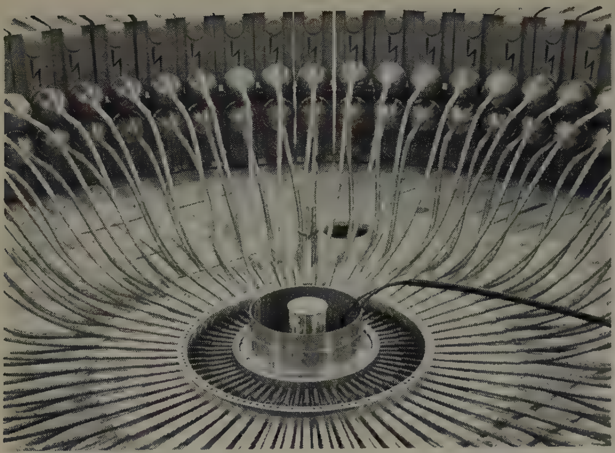


Fig. 2. Coaxial connections from the capacitors to the upper part of the straight discharge tube. (52527)

a capacitor bank across an external spark gap. This bank consists of 120 units of Asea capacitor type CTOA 11. It has a total capacitance of 60 µF and can be charged up to 60 kV.

The aim was to attain the highest possible maximum value of the current in order to achieve effective resistive heating and a magnetic field with powerful confining properties. At the same time the possibilities of using large current derivatives to obtain a quick pinch and powerful adiabatic heating were investigated. This was intended to diminish the impurities in the plasma by effecting a short contact time between plasma and tube wall.

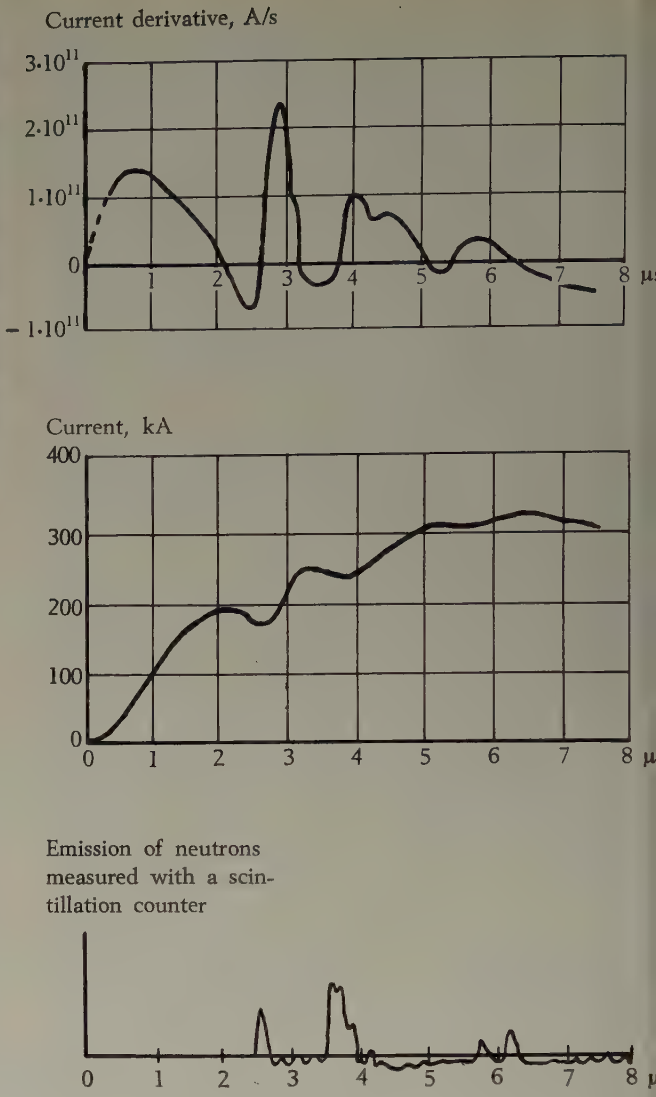
With these aims in mind, the circuit may be designed on the basis of the following considerations. The circuit is almost completely inductive and the current will be

$$i = U\sqrt{\frac{C}{L_K+L_R}}\cdot\sin\frac{t}{\sqrt{C(L_K+L_R)}} = \sqrt{\frac{2\,W_C}{L_K+L_R}}\cdot\sin\frac{t}{\sqrt{C(L_K+L_R)}} \qquad (4)$$

U = charging voltage
C = capacitor capacitance
L_R = inductance in the discharge tube
L_K = short-circuit inductance in other circuits
W_C = accumulated capacitor energy $\frac{1}{2}\,CU^2$

When discharging commences, before the pinch has had time to develop, L_R is low and the current derivative is determined by U and L_K

$$\left(\frac{dI}{dt}\right)_{t=0} = \frac{U}{L_K+L_R} \approx \frac{U}{L_K} \qquad (5)$$



Current derivative, A/s

Current, kA

Emission of neutrons measured with a scintillation counter

Fig. 3. Oscillogram of the discharge period in the straigh tube, showing current derivative, current and neutron emission. (Fr 678)

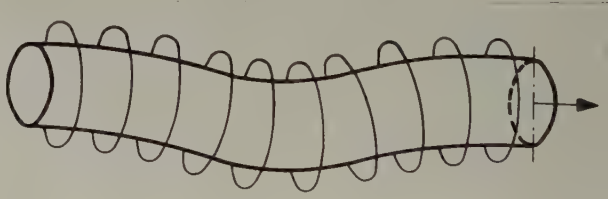


Fig. 4. Diagram illustrating kink instability. (Fr 679)

To attain a high current derivative it is advantageous, according to Eq. (5), to work with high voltages, since inductance in a coaxial arrangement varies only slightly with the thickness of the insulation ($L \sim \ln D_2/D_1$). In this particular case, the inductance is reduced b careful coaxial design to approx. 5 nH (Fig. 2). A Eq. (4) indicates, the maximum value of the curren however, is determined by the energy stored in th capacitor and the tube inductance; after the pinch ha developed, the latter usually dominates completel over L_K. When capacitor energy and tube dimension are fixed, the maximum value of the current is pract cally independent of the selected voltage level an circuit inductance L_K.

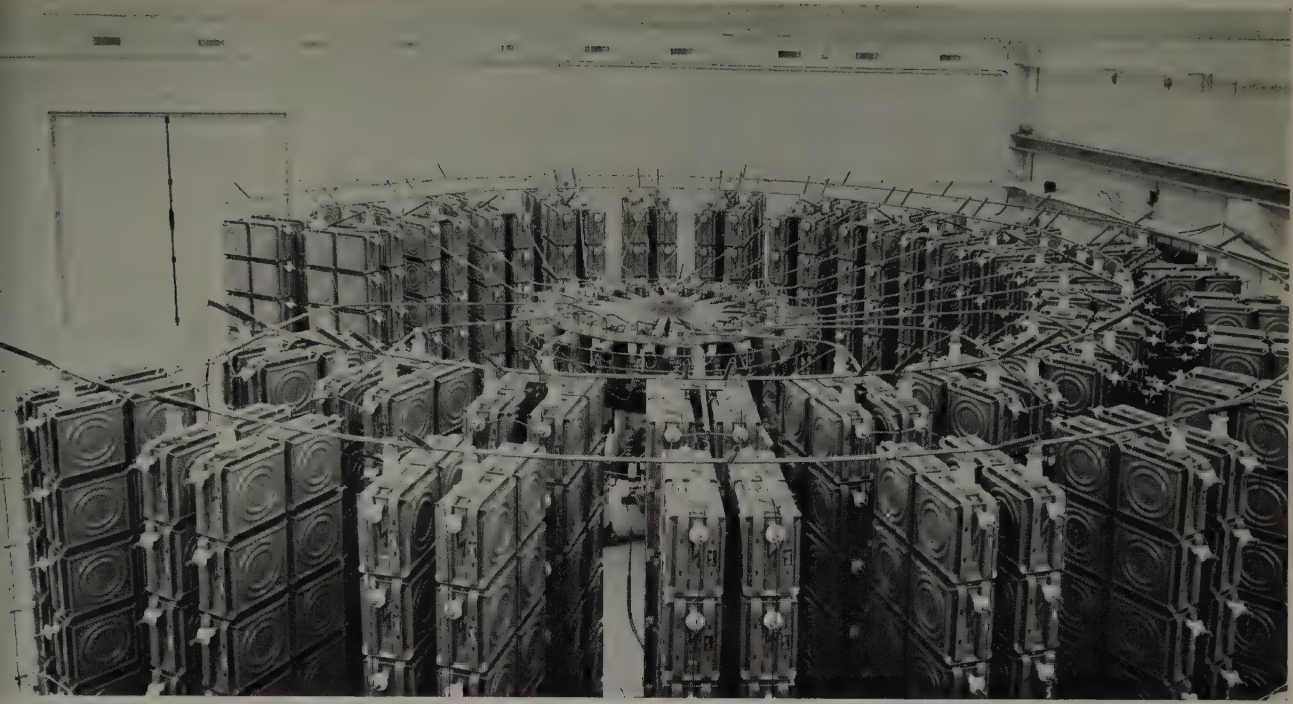


Fig. 5. The 1 MJ energy source with the reactor in the middle. It consists of a bank of 960 Asea capacitors type CTD 2, 35 μF, 7.5 kV. (52455)

The capacitors are of normal Asea type. Connected as described, they are subjected to extremely severe stresses. They have to withstand repeated short-circuits over a low-impedance circuit with currents of up to 10 kA per unit. The effects of the high current forces on internal connections may lead to gradual loosening of weak connections with subsequent current failure and other faults as a result. These capacitors should therefore be designed not only to attain the lowest possible inductance but also to withstand a high discharge frequency and high currents. With capacitor units specially designed for these fusion experiments, the natural frequency is at present approx. 900 kc/s, but with a few minor changes, it should be possible to attain approx. ,400 – 1,500 kc/s. Improvement of the capacitors designed for fusion work will also benefit standard capacitors, especially the series-capacitors for which similar discharge problems exist.

Fig. 3 shows oscillograms of the current derivative, current and neutron emission, the latter recorded with a scintillation counter [3, 11]. The emission of neutrons, taking place simultaneously with the various pinches (indicated by the drop in current in the current oscillogram), means that fusion reactions actually take place in the plasma. This, however, does not prove that the average temperature in the plasma is sufficiently high for a true thermonuclear process to take place, but rather that the fusion reactions would seem to depend on individual particles which have become highly energised on account of plasma instabilities. Even if instabilities lead to fairly large-scale neutron production at low average temperatures, they must still be classed as prejudicial to successful fusion. One of the reasons is that they can lead to a renewal of the contact between the plasma and the walls of the discharge tube, resulting in considerable energy losses from the plasma.

The onset of a simple form of instability, called a kink, is shown in Fig. 4, where a short section of the plasma column is depicted. If a slight bending of the column occurs, it leads to a concentration of the magnetic field of the current on the inside of the bend, which causes the plasma column to be forced against the tube wall. This kink instability can be counteracted by surrounding the tube with a conductive sheath, in which eddy currents are induced. The kink can also be counteracted by means of a magnetic field in the direction of the current. When a movement of the plasma column occurs relative to the magnetic field, eddy currents are then induced in the plasma, thus counteracting the movement. A stabilising axial magnetic field of this kind is formed in the experimental model by means of a d.c. coil placed around the tube.

Another simple form of instability is "sausage-type" instability. If a restriction of the plasma column is brought about, the magnetic pressure increases, thus accentuating the tightening effect. This may eventually lead to a break in current, disintegration of the pinch and subsequent cooling of the plasma.

Investigations of instabilities in straight discharge tubes are far from complete and they will be continued. It should be emphasised that the straight tube should not be considered as the prototype of a fusion reactor, but simply as a means of studying plasma properties.

TOROIDAL DISCHARGE TUBES

A magnetic bottle in the form of a straight tube has one obvious disadvantage: the bottle is open at the electrodes. The plasma is thus polluted by the electrode material, as a result of which energy losses from radiation increase to a disastrous extent. Furthermore, experiments showed that with the type of discharge described it was difficult to transfer a reasonable amount of the energy stored in a capacitor bank to the hydrogen ions in the form of kinetic energy. Plasma is an excellent conductor of electricity, and heat resulting from ohmic heating is unsatisfactory in the case of short periods of discharge, even with currents of the order of millions of amperes.

In experiments with the straight tube, up to five pinches per discharge may occur. During compression, the kinetic energy of the particles admittedly increases, but the major part of the energy increase is lost again during expansion. For the above-mentioned and other reasons, it would be desirable to be able to study pinch effects when the discharges are not contaminated by electrodes and where long discharge times are involved. With this in mind, toroidal discharge tubes came into consideration. It was especially desirable to be able to study the mechanics of heating in plasma. Plasma resistance varies not only with the temperature but also with pressure and frequency and both electrical and magnetic field strengths. It was therefore required of the new experimental model that it should permit the greatest possible variation in these parameters. In this connection, heating by means of electrical or magnetic fields of very high frequency, corresponding to the gyro-relaxation frequency of the plasma particles [4, 5], for example, is of particular interest.

As mentioned earlier, the energy released when fusion takes place is about two hundred times as great as the kinetic energy the deuterons must have for the thermonuclear reactions to take place. If fusion processes are to be economic as far as the generation of heat and electricity is concerned, it is not sufficient for energy transmission to work satisfactorily; it is also imperative that the hot plasma be contained in a magnetic field as long as possible without contact with tube walls etc., so that as large a number of nuclear reactions as possible can take place.

That this is necessary can be demonstrated by the following example. The degree of efficiency for the transmission of energy from an electrical primary circuit to the plasma may be estimated to be ten per cent and the degree of efficiency for the generation of electrical energy from thermal energy, twenty-five per cent. After conversion at a thermal power-station the electrical energy then available will be only $200 \times 0.10 \times 0.25 = 5$ times greater than that necessary to heat the plasma particles. This means that at least one fifth of the deuterons must react if the process is to produce a surplus of energy. The reaction time necessary for this to happen depends on both pressure and temperature and therefore no reliable figure can be quoted, but it may be assumed to lie within a few powers of ten of the value 1 second. This example is extremely simplified. Radiation losses have been ignored, as well as the fact that a part of the fusion energy directly contributes to the heating of new particles.

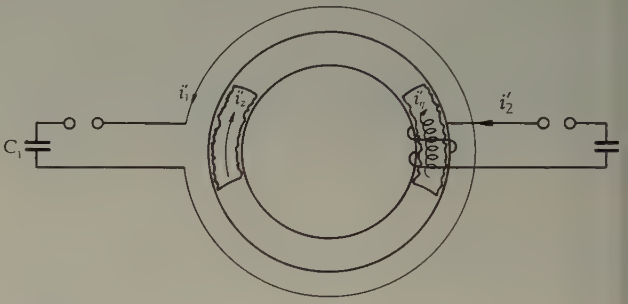


Fig. 6. Diagram showing guide and coil currents i'_1 and i'_2 together with corresponding plasma currents i'_z and i'_φ in the tube. (Fr 680)

In spite of these flaws in the example quoted, it should be apparent that the study of heating phenomena and long-term enclosures is of the greatest importance. It has been pointed out [6] that it may be necessary to work with continuous processes to achieve economic energy production.

Long periods of confinement are also important if experimental models are to work satisfactorily. The longer the nuclear process can be kept going, the easier it is with the aid of various means of measurement, to get a clear picture of the conditions in the plasma. This particularly concerns measurements of plasma temperatures and the energy spectrum, as well as speed components of the neutrons which are emitted from the reactor.

THE UPPSALA REACTOR

Fig. 5 shows a part of the experimental arrangement in the form of a capacitor bank in which the energy is stored. Other items of equipment which can be seen are cables, spark gaps and a wooden framework into which the reactor has been built. In this reactor, the construction of which began in February 1958, the gas is ideally contained in a magnetic bottle, as in the above-mentioned example, and heated by means of currents generated by discharges from a capacitor bank. To avoid using electrodes, however, the current is, in contrast to the first reactor, induced in the gas, which is contained in a toroidal porcelain cylinder.

After it has been partly ionised, the gas acts as a short-circuit secondary winding in two different transformer systems. It is thus possible to induce two different currents in the deuterium. The primary winding of the one system consists of conductors which are referred to as "guides" (Fig. 6). When the capacitor C_1 is discharged, the current i'_1 flows through the guides and results in the current i'_z in the plasma. The other primary winding consists of coils placed around the tube. One of these coils can be seen on the right in Fig. 6. An alternating current i'_2 in the coil induces a corkscrew current i'_φ in the plasma.

The discharge tube was enclosed in forty such coils, lying very close to each other. Eighty guides were fitted on top of the coils (Fig. 7). Coils and guides are supplied from a capacitor bank of 1 MJ (960 capacitors of type CTD 2, 35 μF, 7.5 kV) which is divided up into forty separate groups by means of large resistors, in order to limit fault currents in the case of short circuits during the charging period.

Each group is divided up into 4 sub-groups of 6 units, which are symmetrically arranged round the earth potential and charged with max. ± 7.5 kV (Fig. 8). A coaxial cable from each capacitor group leads to the reactor. The capacitor energy can be discharged through either the guide, or the coil, system, or by connecting these systems in series or in parallel. The number of connection variations thus available has been further increased by the division of each of the forty coils into four coil parts, which in turn can be mutually connected in series or in parallel. This system allows of about twenty simple synchronous connections; i.e., connections where guide, and coil, currents are induced simultaneously and have the same frequency.

It is also possible to start the guide, and coil, systems at different times, either with different or with approximately similar frequencies. It is, for example, possible to allow the coil system to oscillate at such a low frequency that the magnetic field of the coils can be conceived of as a stabilising d.c. field during the discharge of a part of the capacitor bank through the guides in order to induce a current i_z (the z-axis is the centre-line of the tube).

It is possible by means of these reconnections to vary the discharge frequency from several hundred to several thousand cycles per second in small steps. The maximum current in the direction of the z-axis is approx. 500 kA. The effect of the coils is to add a current component which rotates about the z-axis, resulting in helical passes for the total current. The pitch of the helix can be varied in small stages. In the extreme case where only the coils are connected, the component of the current in the z-direction is only a few kA, while a current of approx. 7,000 kA circulates round the z-axis.

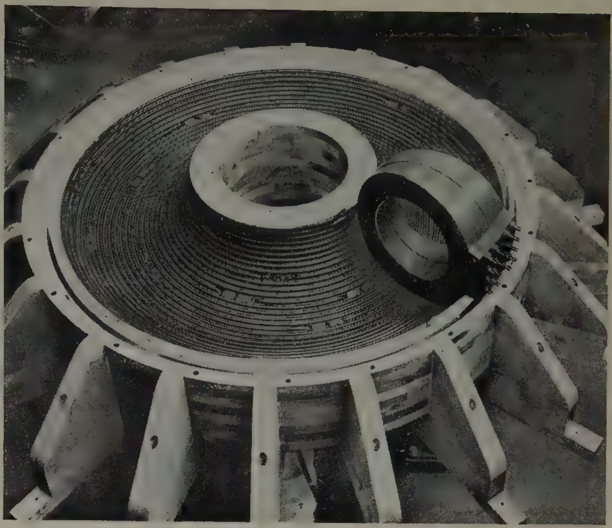


Fig. 7. Part of the wooden framework with guides and two of the coils. (52456)

The fact that it is thus possible to introduce shear in the current path is of great importance if the instabilities in the plasma which arise out of particle drift in non-homogeneous magnetic fields are to be avoided. In other experimental reactors such as the American Stellarator [7], for example, the shear is achieved by means of winding the guides round the tube instead of superimposing the current due to one system on the current due to another.

The switching on of large currents presents a technical problem of some difficulty in the designing of reactors for fusion experiments. In this case a maximum current of 1,600 kA at 15 kV is switched on by igniting forty spark gaps, one in each group of the capacitor bank.

The spark gaps have graphite electrodes which distribute the current over a large area, which means that there is little burning of contacts and any tendency to form beads or other surface irregularities is obviated. A steep 25 kV pulse with a time to half-value of 1 – 2 ms causes ignition by striking a graphite electrode, which is placed immediately between the main electrodes. The gaps spark over approx. 1 μs after the initial igniting pulse with a margin of about ± 0.5 μs. When ignition has taken place across some of the gaps, the current in the appropriate guides and coils induces a counter-voltage in other groups where ignition has not taken place, with the result that the voltage of the latter is reduced and sparking is made difficult or even impossible. It is therefore necessary to bridge the gaps with capacitors which are so designed as to maintain the gap voltage for a time corresponding to several times the scatter in the sparking time.

The gaps are far from ideal. They require constant attention and adjustment, but despite this, they would appear to be suitable for use in models intended for a relatively limited number of discharges only. Work is at present going on in many places with the development of better switching elements.

The ignition impulse is provided by a duplicated electronic system, both parts of which allow the guide, and coil, systems to be tripped with a continuously variable time displacement of between 20 μs and 5 ms.

The mechanical forces present another problem. In the present reactor the instantaneous electric power input during a few ms is approx. 15,000 MVA, and this power is released within a very restricted space (approx. 0.5 m^3). The field strength in the reactor is approx. 3 Wb/m^2. In such conditions, the powerful compressive forces between parallel conductors with the same current direction and the powerful expanding forces between conductors with different current directions present a serious problem. The times to half-value of the discharges are so long that the inertia of the mass is not sufficient to limit deformation to the elastic range of the constructional material, and this has made comprehensive statical calculations necessary. This can be illustrated by the following figures, which have been calculated for certain ideal load cases.

If a discharge does not strike – as may be the case especially when the gas pressure is low – each guide is subjected to a force of approx. 14,000 kg directed towards the centre-line of the system. The aggregate force exerted on eighty guides will then be approx. 1,100,000 kg. To ensure that the tube is not exposed to such high forces, the coils have been placed between the tube and the guides, and have to take up the pressure. If the discharge strikes and the coupling coefficient between the primary and the secondary circuit is 0.8 – this is also quite conceivable – the expansion forces on each guide will be approx. 10,000 kg; i.e., 800,000 kg for the whole system. This force is taken up by an extremely robust wooden framework, in which the whole guide system is embedded. The framework has also to withstand a force of up to approx. 3,000 kg per conductor, which tends to expand the whole guide system.

The flow through the coils generates a tangential expansion force of approx. 3,200 kg per coil, and attraction between the coils amounts to approx. 30,000 kg per coil. Lack of symmetry tends to increase the forces at certain places.

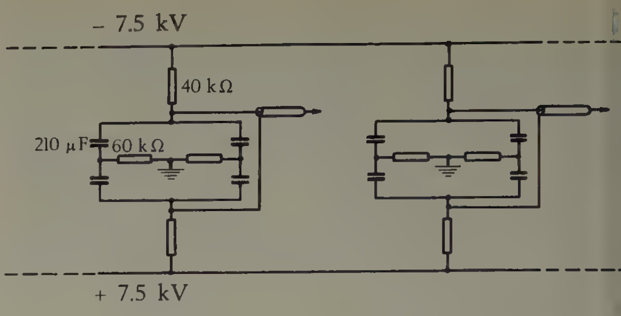


Fig. 8. Diagram of the division into groups of the 1 M energy source. (Fr 681)

The designing of toroidal discharge tubes presents man difficulties. In the case in question, the tube is made o porcelain (large diameter 102 cm, small diameter 26. cm), partly to prevent currents being induced in th tube wall by the guide and coil systems. A spare tub of copper has been made. This has been divided up an the parts have been insulated from each other to preven these currents arising. The joints, however, are troublesome from the point of view of obtaining a vacuum and in any case they can be expected to be short-circuited by internal arcs during the discharge.

The first model of the experimental reactor had no iro core. This was a necessary omission, since a large numbe of wiring variations was required, but, as a result, th reactor suffered from reduced efficiency in transmissio of energy from the capacitor bank to the plasma. Thi

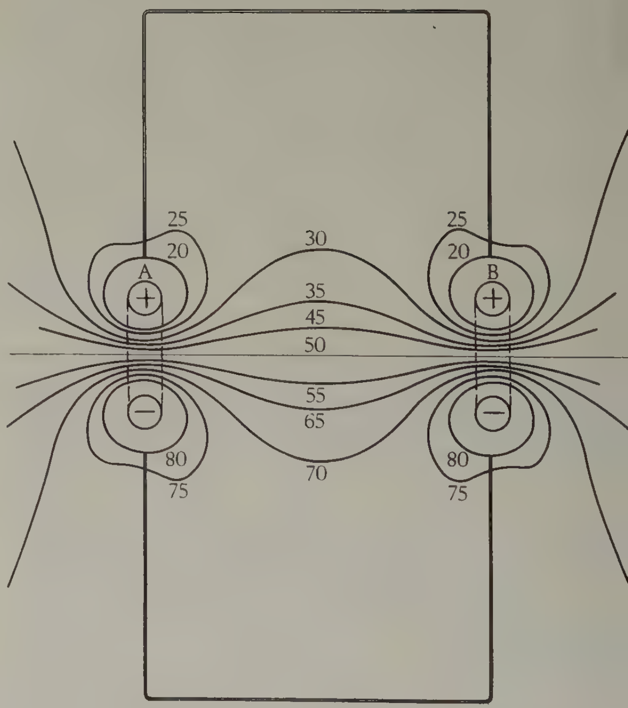


Fig. 9. Magnetic field of a mirror machine system with iro yoke. The difference between the figures is equal to the percentage of the flux which moves through the space determined by the rotation of the appropriate lines. (Fr 682)

fficiency is proportional to the square of the mutual iductance, and according to calculations it should be ossible to improve it considerably, even without reorting to an iron core, by means of later modifications ıvolving an increase in the ratio between the large and mall diameters of the toroid.

ın improvement in energy transmission can probably lso be achieved by placing the guides inside the coils. 'he guide system could be designed in such a way that : could withstand the compression impact on its own; or example, it could be divided into trapeziform secions. What is more, the torus formed by the guides ould at the same time serve as a discharge tube if some orm of outer packing were fitted. The insulation around he guides would then have to have a low vapour presure and be able to withstand high temperatures and on bombardments. Several insulation materials exist vhich seem to meet the case.

Vhen a plasma temperature of the order of a million egrees has been reached, various forms of high-frequeny heating are effective. The gyro-relaxation process, lso called magnetic pumping, is perhaps of particular ıterest. This involves irreversible adiabatic compressions f the plasma in step with the magnetic field variations. pace for insertion of high-frequency coils has been left ı the Uppsala reactor between the porcelain toroid and he coil system. In particular, it has been planned to use metal casing around the discharge tube not only to ounteract plasma instabilities, but also to serve as a oil during high-frequency heating. Before this can be lone, however, many difficulties remain to be overcome vith regard to the worst plasma instabilities.

IIRROR MACHINES

ınother interesting type of "magnetic bottle" is the mirror machine" upon which research has been done t the High-voltage Laboratory in Ludvika. Fig. 9 shows magnetic field of a mirror machine recorded in an lectrolytic tank. Two coils A and B produce a magnetic ield which is strong at the coils, but relatively weak in he area between the coils. It can be proved that plasma articles are enclosed in a field of this type. They are ıade to follow the lines of magnetic force and cannot ross them. If the particles, during their motion along he lines of force, enter areas where the lines of force re close, they are reflected into areas of lower magnetic ensity, and are thus contained within the field. In Fig. 9 yoke for the magnetic return flux has been sketched ı. At the same time, it can serve as a vacuum casing nd, if necessary, absorb mechanical forces from the coils.

ig. 10 shows a mirror field variant of an entirely differnt type. This arises when the currents in the coils have opposite directions. It can be demonstrated [8] that a plasma confinement in a field of this type is completely stable. Particle losses at low plasma temperatures are small, which makes this "cusped geometry" configuration very suitable for fundamental plasma investigations. Characteristic of this configuration is the fact that all plasma surfaces facing the magnetic field are concave.

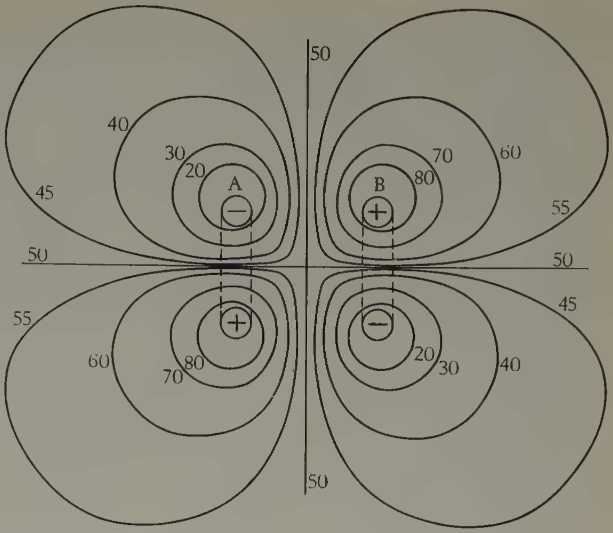


Fig. 10. Cusped geometry field. (Fr 683)

If really long periods of confinement are desired, a capacitor discharge system is unsuitable, and rotating machines must then be resorted to. Mirror machines can be supplied from d.c. motors, but the magnetic energy in the mirror field is limited by the current available from the machines. There is therefore a temptation to work with multi-phase mirror or cusped fields. Such fields have been investigated, and perhaps the simplest configuration, which has the great advantage that it allows of continuous service, is dealt with briefly here.

It is possible to conceive a series of coils arranged around a toroidal tube and connected to a three-phase alternating voltage machine, for example, a powerful shortcircuit generator. In this way, fields varying in time and space can be obtained within the coil. As Fig. 11 shows,

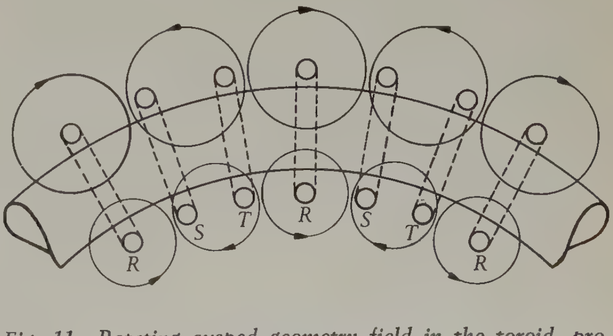


Fig. 11. Rotating cusped geometry field in the toroid, produced by three-phase alternating current. (Fr 684)

the field has a cusped geometry. It will readily be seen that the field will not disintegrate when the current passes through zero. It maintains – apart from a few minor harmonic deformations – constant shape and strength. The field, however, rotates slowly along the tube and any plasma confined within it naturally does the same. The toroid with the rotating plasma can of course be replaced by a straight tube, in which the field and plasma have a relatively low translatoric speed. High field intensities can be obtained in the tube, especially when an external iron yoke is used, while voltage gradients in the plasma remain small. In this way, conditions are made favourable with regard to preventing electrons from being accelerated to such high energy levels that the field can no longer contain them, resulting in large energy losses from the plasma. A field of this sort can be combined with high-frequency heating of the plasma.

There are yet more possibilities, for much unexplored territory in the world of fusion research still exists. A fairly detailed, very readable account of this subject is to be found in a book [9] which was published in the autumn of 1958. There is no doubt that the field of fusion research will have the greatest significance for the whole of mankind, since it will answer the question: "Shall we succeed in tapping unlimited sources of energy?"

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(Z 10937)

SVEN GYNT AWARDED THE IVA MEDAL

On 22nd October 1959, Mr Sven Gynt was awarded the Gold Medal of the Swedish Academy of Engineering ciences (IVA), primarily for his work on the development of large electrical machines at Asea. The medal was presented by His Royal Highness Prince Bertil at he Annual General Meeting of the Academy, see the lustration. In addition to Mr Gynt, between the years 927 and 1959, sixteen other engineers working for the Asea Group have received this award for outstanding echnical achievements.

Mr Gynt has shown a rare combination of theoretical nsight and sound practical judgment in his work as a esigner. Examples of major works which have benefited o a great extent from Mr Gynt's pioneer activities are he 150 MVA generators at Stornorrfors and the generator in the High-power Laboratory at Ludvika which as a short-circuit power of 2,500 MVA.

Mr Gynt's work has been concerned with many of the omponent items in large electrical machines. For example, he has worked on the designing of windings and winding insulation, in particular compound-impregnated mica-tape-insulated coils. Another field in which Mr Gynt has done excellent work is in the designing of thrust bearings for large electrical machines. At an early stage, Asea broke new ground in this field by producing their sprung segment bearings. However, even in bearings of this type difficulties were sometimes experienced as far as oil lubrication was concerned. The bearings were fitted with external oil pumps, and in spite of the fact that these pumps were so placed in the circulation process that the leaking in of air appeared to be impossible, Mr Gynt proved that air did in fact leak in through faults in the packings, thus allowing the temperature of the bearings to rise with the resultant risk of damage. Mr Gynt's design for self-lubricating bearings, which was based on the centrifugal forces in the oil, was brilliant in its simplicity. With its introduction, all the difficulties connected with oil lubrication ceased, and, at the same time, the omission of the external pumps implied a considerable economic gain.

THE HIGH-VOLTAGE D.C. TRANSMISSION SCHEMI ACROSS THE ENGLISH CHANNEL

Ingvar Lidén, Converter Department, Ludvika

U.D.C. 621.315.051.0
Asea Reg. 730

A few comments on the work already completed on the d.c. link across the English Channel, with particular reference to the type-tests on the ionic valve and the arrangement of the equipment in the French station.

One of the milestones in the completion of the d.c. transmission system beneath the English Channel (see Asea Journal 31(1958):6, pp. 70–74) has now been passed in that the first major delivery of material has been made to Rouen, after a period of storage, for dispatch from there to the site at Echingen outside Boulogne. The items delivered on this occasion were four valve stands, valve platforms, wall bushings, insulating transformers and other material required in the initial stages of erection. The customer's buildings are practically complete and the Asea erectors are at the site in order to organise erection and to carry out a number of preliminary tasks such as the grouting of the fixtures for the equipment and the cable ladders.

The equipment supplied by Asea will be set up in the French station as shown in Fig. 1. As has been mentioned previously, the installation comprises two converters, each rated at 100 kV, 800 A, d.c., in a six-pulse, two-way connection. They are connected in series on the d.c. side. The two valve groups are set up in the valve bay in the foreground. The wiring for the six-pulse, two-way connection for the right-hand group can also be seen.

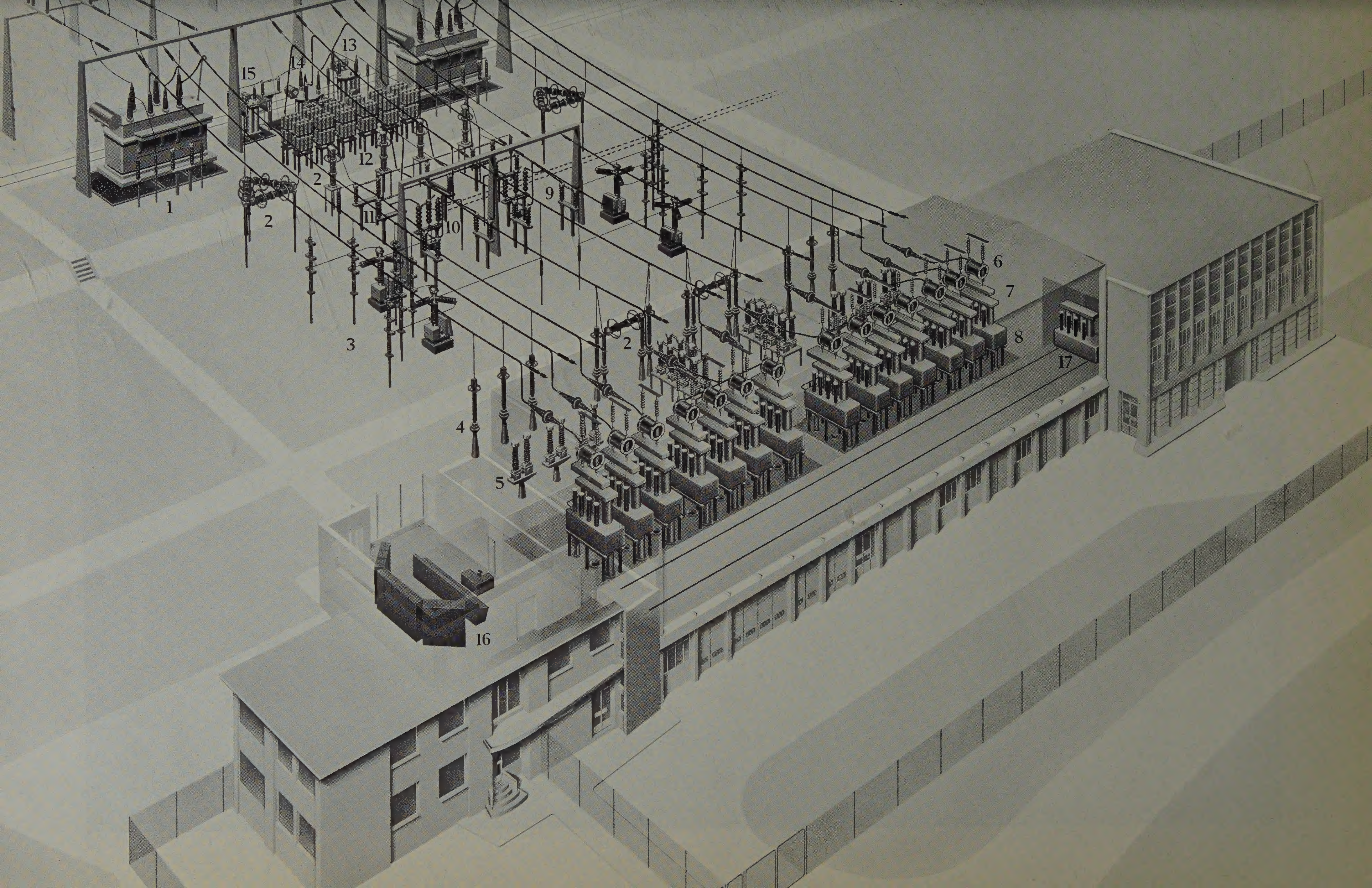
In the British station too, building work is in full swing and the erection work to be carried out by Asea will be started this summer. The time-table for this station has been somewhat delayed in relation to that of the French one since work had to be carried out simultaneously on two other major projects intimately connected with the d.c. link with France, that is, the 275 kV, a.c. transmission line from London via Canterbury to a place in the neighbourhood of Dungeness, and the nuclear power-station there. The co-ordination of these projects gave rise to problems as far as the siting of the station and the lines was concerned, and the matter has been furthe complicated by the fact that special measures had to b taken to preserve the natural amenities of the regio As far as the d.c. link is concerned, this means that is expected to be ready for regular service in time f the winter load of 1961.

It has been decided to utilise the period between t completion of the two converter stations by arrangin trial running at the French station after it has been completed. After minor modifications to the circuits, it possible to run the one converter group as a rectifi connected to the second group, which is operated as a inverter. Thus, energy is taken from the network, converted in the rectifier and inverter groups and fed o into the network again. In this way, it is possible, at th earliest possible stage, to check that the equipment functioning correctly, to instruct and train the personne and to obtain quantitative information on the effect the station on the grid etc.

As far as the Asea deliveries are concerned, it may b mentioned that, in accordance with the contract, typ tests were carried out on the ionic valves during th spring and early summer of 1959. The tests showed tha the type of valve selected fulfilled the demands made o it with a fair margin, and the manufacturing of the

1 Main transformer
2 Surge diverter
3 Damping equipment for the valve group
4 Voltage-divider for measuring
5 Insulating transformer
6 Anode reactor
7 Current-divider
8 Valve
9 Isolator for valve group
10 By-pass switch
11 Cable isolator
12 Capacitor battery for the d.c. damping circu
13 Impedance for the d.c damping circuit
14 Smoothing reactor
15 Earthing impedance
16 Control room
17 Degassing room

Fig. 1. Converter equipment in the French station. (T illustration may be reprinted only with the permission Électricité de France.)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valves to be supplied could therefore be continued in accordance with the programme.

Fig. 2 shows the valve set up for surge tests in the Asea High-voltage Laboratory at Ludvika. The four anodes are enclosed in the white cylinders, which, together with the box situated above them, lead the jets of cooling air around the anodes. The brown cylinders to the le of the picture contain the voltage-dividers for the ele trodes in the anode insulators. The valve tank with th mercury cathode and the auxiliary apparatus for exc tation, grid-biasing voltage, maintenance of the vacuur and temperature regulation are built into the lower pa of the framework. The current-divider is suspende above the valve. The final colours of the valves for th Channel scheme will not be those shown in the illu tration.

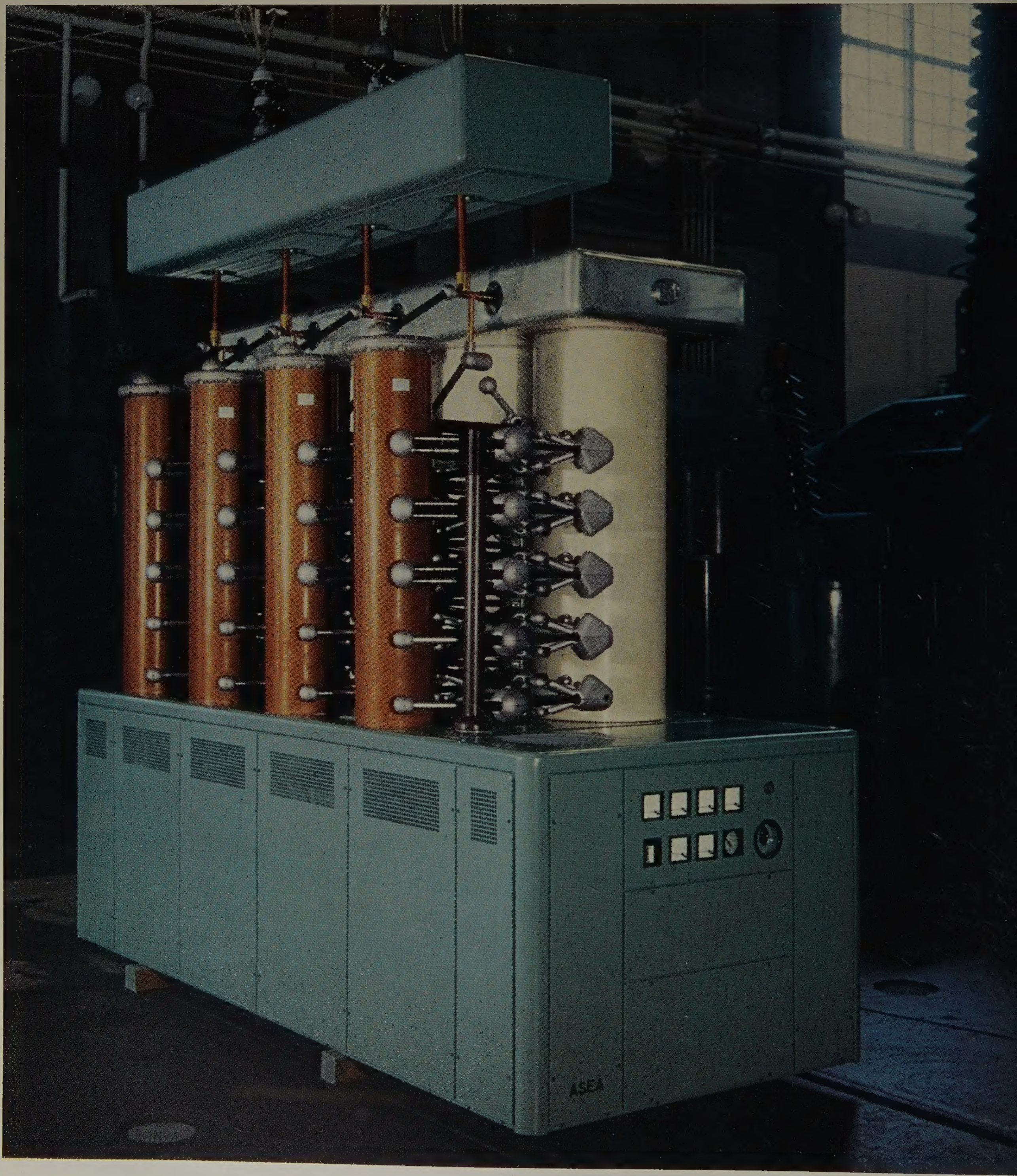
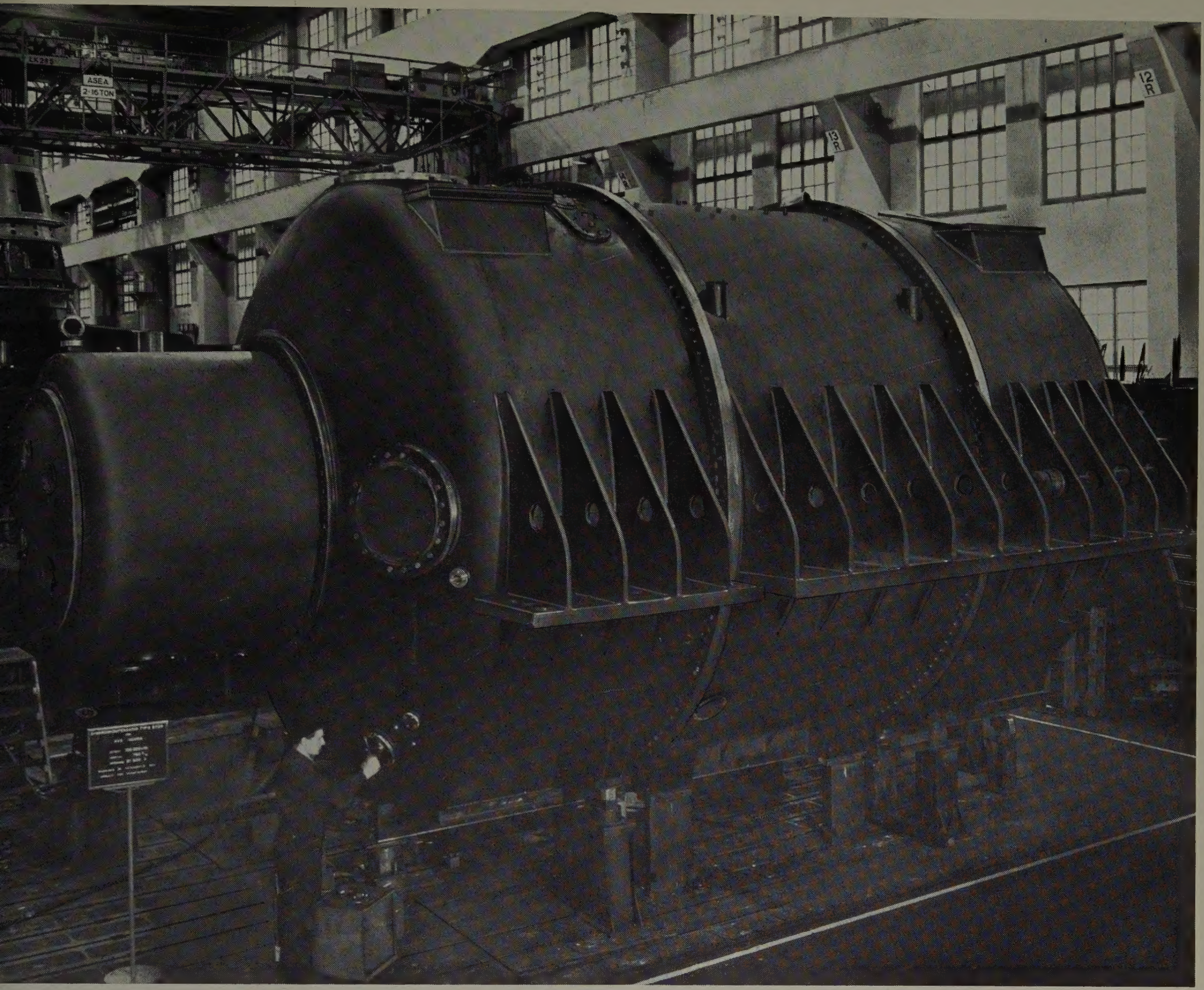


Fig. 2. Prototype of high-power ionic valve for 100 kV, 800 A, in six-pulse, two-way connection.



(54563)

NEWS IN BRIEF

HYDROGEN-COOLED SYNCHRONOUS CONDENSER RATED AT 00 MVA, 21.5 kV

A 100 MVA hydrogen-cooled condenser now under manufacture in one of he Asea factories at Västerås and will e handed over to the Swedish State ower Board this year. The illustration hows the stator housing of the machine et up for pressure-testing with water (6 tm above atmospheric pressure) and for ests to ensure that it is gas-tight.

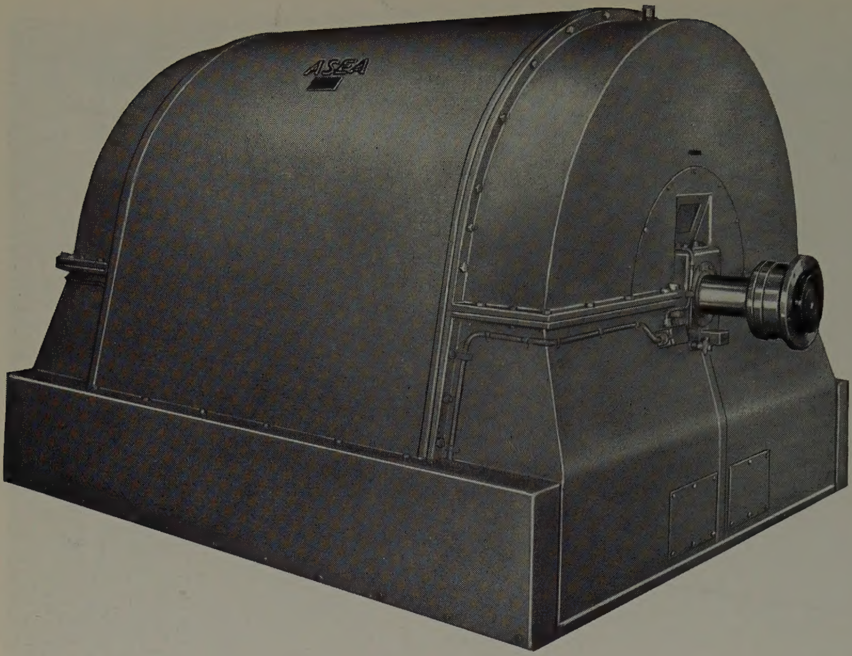
he machine will be the fourth of the rge hydrogen-cooled synchronous condensers which the Swedish State Power oard has ordered from Asea for use in e 400 kV transmission system from wedish Lapland to the south of the ountry. As was the case with the other achines supplied, it is designed for 0 r/m, 50 c/s. However, the rated voltage is 21.5 kV while the highest rated voltage for the previous machines is slightly lower, being 21 kV.

Of the synchronous condensers previously supplied, the first two had separate converters for the excitation, while the third machine was built with a directly-connected exciter. The latter design was also adopted for the fourth unit described here and which is to be set up in the same station as the last machine supplied. The separate, gas-tight exciter housing, which will also contain the slip-ring gear for the synchronous condenser, can be seen to the left of the illustration. The main machine and the exciter have separate cooling systems with built-in water coolers for the circulating hydrogen.

The synchronous condenser which is now under construction will work with a hydrogen pressure of 1 atm above atmospheric pressure for the rated power of 100 MVA when over-excited. The machines previously supplied have a rated power of 75 MVA at a hydrogen pressure of about 0.1 atm above atmospheric pressure. The heating in these machines is low taking into consideration the values quoted for power and hydrogen pressure, and they can also be used for 100 MVA at a hydrogen pressure of 1 atm above atmospheric pressure. This has been confirmed by temperature tests carried out on site in the case of the machines supplied, of which the first has now been running for seven years.

When under-excited, the new machine is to be able to work with a load of 67 MVA at 18.9 kV, which corresponds to 87 MVA at the rated voltage of 21.5 kV.

Asea Reg. 4423



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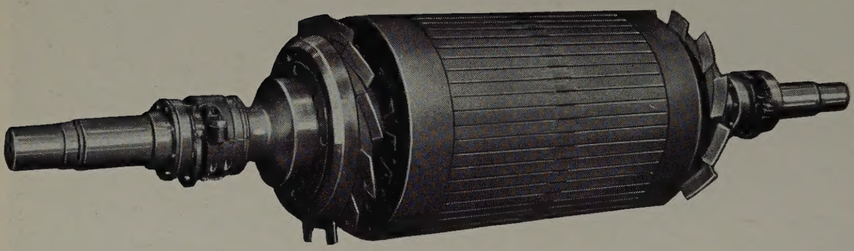

(51450)

LARGE 3,000 R/M SQUIRREL-CAGE THREE-PHASE MOTORS

In 1958 and 1959, Asea supplied five large squirrel-cage induction motors to Luossavaara–Kiirunavaara AB for direct connection to Atlas Copco screw-type air compressors. The motors are rated at 2,600 kW, (3,500 h.p.), 2,980 r/m, 50 c/s, 3,000 V. Two of them are duct-ventilated with inlet and outlet ducts, while three are totally-enclosed having a closed air circuit system with water-cooled air coolers built into the bearing end-shields. The motor has two bearings, two shaft-ends and its own base-plate. Each compressor consists of a low-pressure part and a high-pressure part, one at each end of the motor.

The illustrations show a complete motor and a rotor with axial fans and bearings in place.

The stator has a diamond coil winding in open slots, with class B insulation. The coils are vacuum-pressure impregnated in an asphalt compound, that is to say, the insulation is of the same quality as in the large Asea generators. The squirrel-cage winding of the rotor has rectangular hollow conductors, which also serve as channels for leading cooling air to the centre of the machine. The conductors have transverse slits, which increase the length of the current path in the conductors and consequently increase the starting torque. The motors have sleeve bearings which are lubricated by circulating oil from an oil system which is common to the compressor and the motor. Temperature detectors are built into the stator winding and bearings.

Each motor has its own transformer for 20,000/3,000 V. The motors are started direct-on-line, the motor voltage then being approximately 2,500 V because of the voltage drop in the transformer, and the starting current approximately 2,500 A, or 4.5 times the rated current of the motor. The starting time is approximately 30 seconds.

Motors of the same style are also used for pump drive, and the maximum rating is about 5,000 kW.

Asea Reg. 4431

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